ATKINSON

Investigation of a
Three-Hinged Arch Bridge

Civil Engineering
B S
1906

INVESTIGATION

OF A

THREE-HINGED ARCH BRIDGE

BY

JESSE CAMPBELL ATKINSON

THESIS

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This is to certify that the thesis, prepared chiefly under the immediate supervision of Assistant Professor Ketchum, entitled INVESTIGATION OF A THREE-HINGED ARCH BRIDGE by JESSE CAMPBELL ATKINSON is approved by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

Ira O. Baker.

Head of Department of Civil Engineering

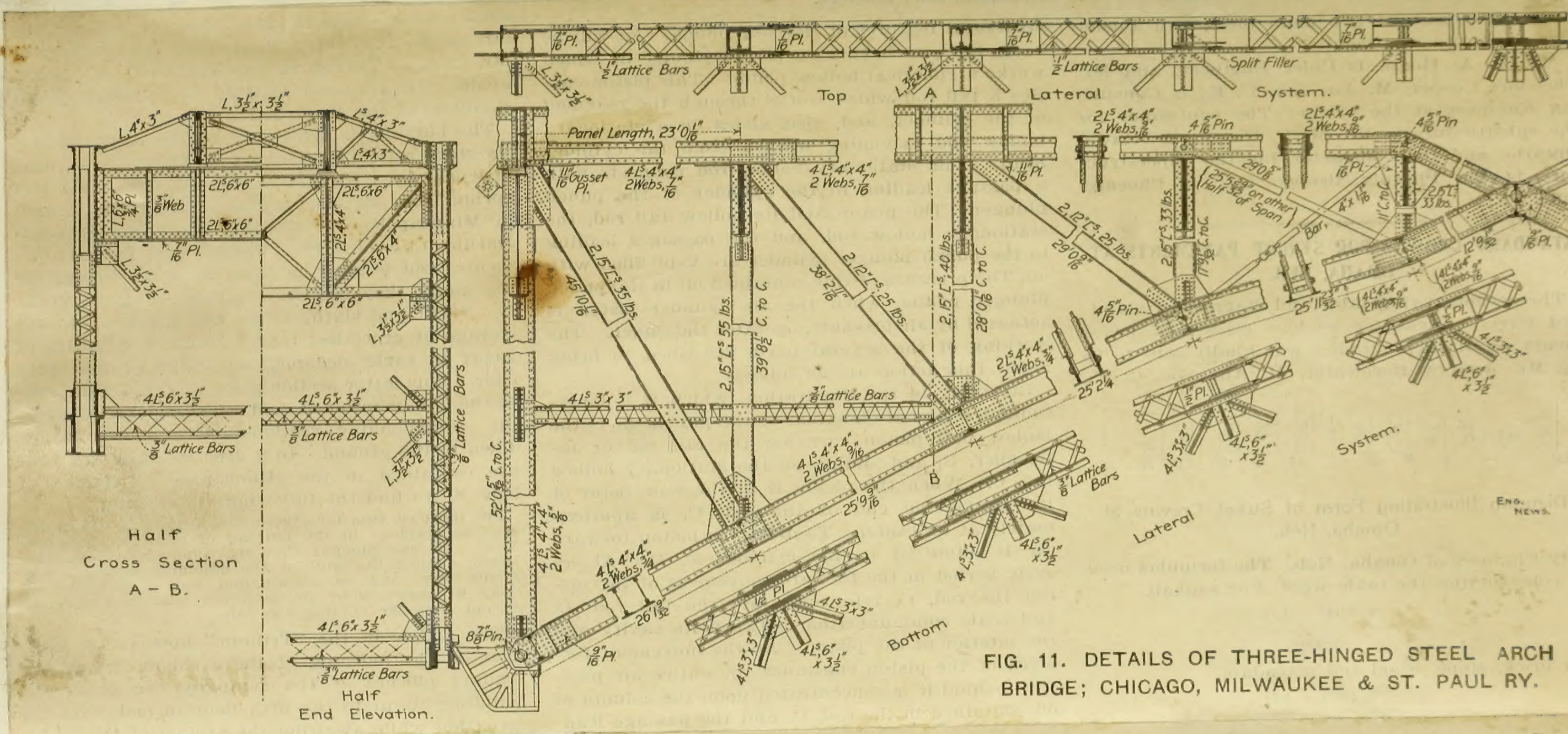


FIG. 11. DETAILS OF THREE-HINGED STEEL ARCH BRIDGE; CHICAGO, MILWAUKEE & ST. PAUL RY.

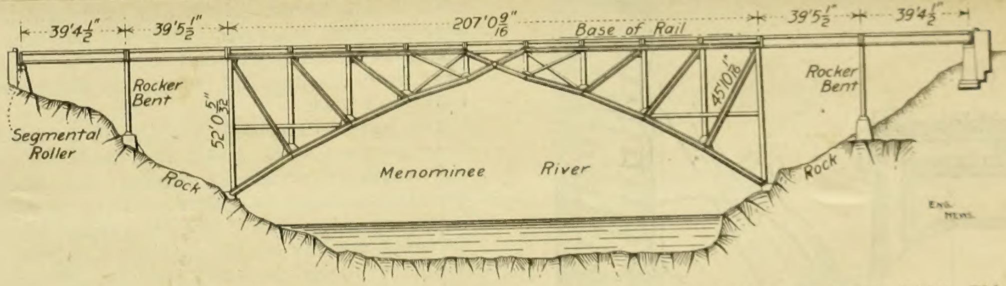


FIG. 10. THREE-HINGED STEEL ARCH BRIDGE; CHICAGO, MILWAUKEE & ST. PAUL RY. C. F. Loweth, M. Am. Soc. C. E., Engineer and Superintendent of Bridges and Buildings; Phoenix Bridge Co., Phoenixville, Pa., Contractors.

Introduction

The bridge which is the subject of this investigation was designed under the direction of Mr C. F. Loweth, Engineer and Superintendent of bridges and buildings of the Chicago Milwaukee and St. Paul Ry.

The bridge was built by the Phoenix Bridge Co of Phoenixville Pa. in the fall of 1902.

The superstructure is of medium steel of a tensile strength of from 60000# to 68000# and was proportioned throughout generally in accordance with Coopers Specifications for Railway Bridges, (1901 edition) and for a live load of two consolidation class E. 50 locomotives, followed by a uniform train load of 7000# per lineal ft. of track. This loading was adopted to provide for a heavy ore traffic.

The bridge is a deck span of nine panels of 23'-0$\frac{7}{16}$" each, making a total length of 207'-0$\frac{7}{16}$". The trusses are spaced 22 ft. c. to c. and have a height of about 52 ft.

The hinge pins are $8\frac{7}{8}''$ diameter, and those in the fourth panel are $4\frac{5}{16}''$ diameter. The chords consist of web plates and angles, and are laced top and bottom. The end posts are built in the same way except that the angles are riveted inside the web plates. The vertical posts and diagonals consist of channels, laced, except the diagonals in the fourth panel which are eye bars.

The floor beams are plate girders, with the exception of the end floor beams, (which are trusses,) and are riveted to the inside of the posts

The stringers are plate girders, spaced 8 ft. apart and are supported on top of the floor beams. They have rigid cross frames and top lateral bracing, and are also braced with struts from the chords at each panel point.

The total weight of metal in the main span exclusive of the approach spans is about 240 tons. The approaches each consist of two plate girder spans of $39'-4\frac{1}{2}''$ and $39'-5\frac{1}{2}''$ respectively, supported by an intermediated rocker bent, and have

segmental roller bearings at the abutments

The live load stresses were obtained from the uniform loading, since that gives maximum stresses as will be seen from the following. The total weight of two consolidation engines is 710,000.# (See Cooper page 5.). The average load per lineal ft. is 710000 ÷ 109 = 6512.# The uniform load per lineal ft. is 7000.#

In the investigation the dead load stresses were obtained by means of a stress diagram as shown on page 7.

The wind stresses shown on the stress sheet were much larger than those obtained from Coopers loading. Since the loading used was not known, the stresses were obtained from Coopers loading.

All stresses are computed in thousands of pounds.

The investigation was made entirely from a general drawing, hence much information necessary for an accurate investigation was lacking. On account of this it was found necessary to design the stringers and floor beams from

the data given.

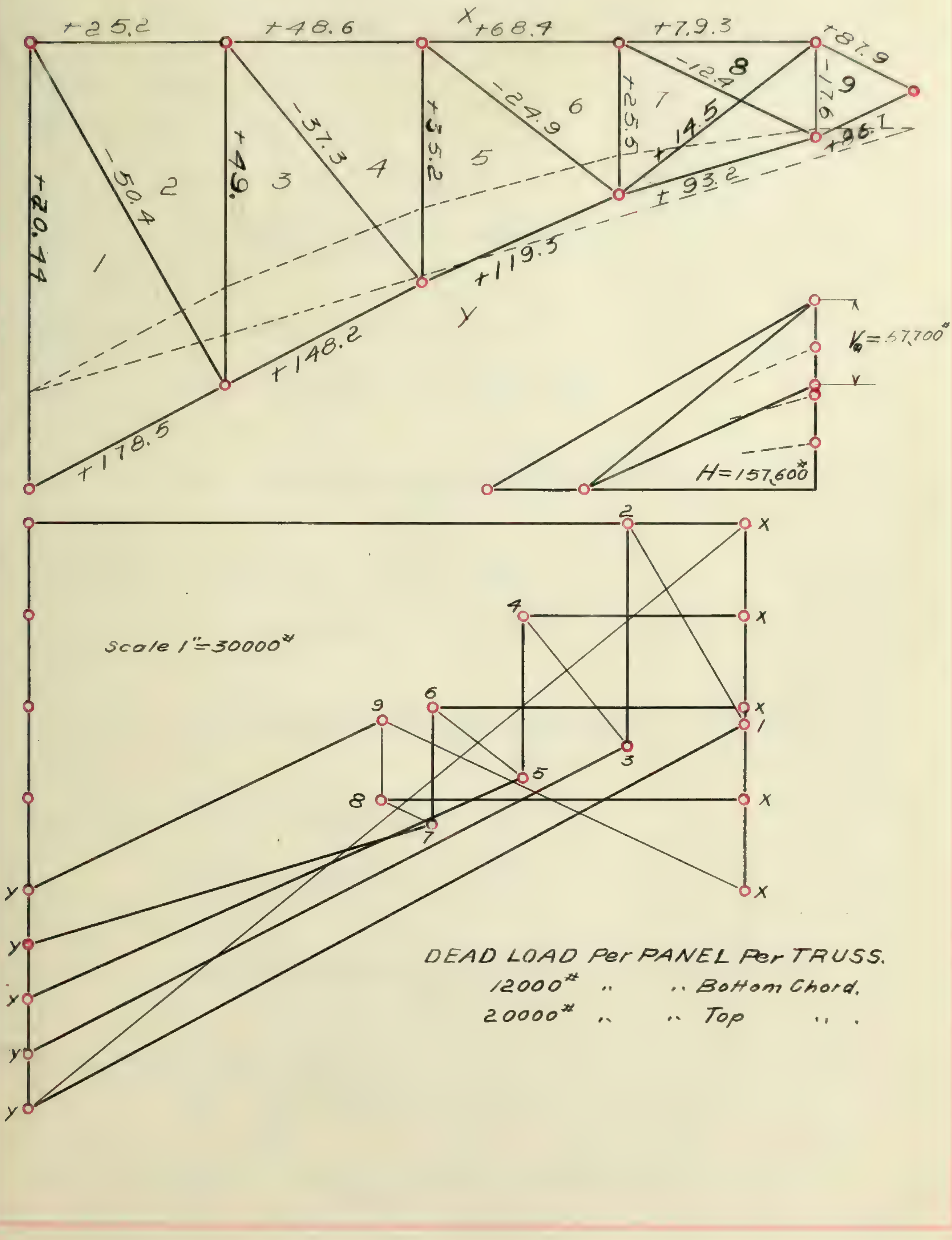
The low efficiencies in a number of cases, due to lack of rivets were probably corrected in the detail drawings.

Summary of Weights.

Ref No.	Member	No. of Pieces	Total Weight Main Mem.	Total Weight Details	Details % of Main Mem.
1	Top Chord	4	42260	32076	75.9
2	Lower ..	4	81988	57099	69.6
3	Posts	20	57562	20148	35.
4	Diagonals	6	38169	5929	15.5
5	Sub Struts	4	4540	2753	60.6
6	Portals	2	15778	5159	32.7
7	Floor Beams	10	42309	5355	12.6
8	Top Laterals	20	4437	833	18.7
9	Bot. ..	20	18754	5411	28.7
10	Sway Bracing	20	3750	1661	44.
11	Stringers	18	61940	11742	18.9
12	Pins & Nuts			4665	100.
13	Pedestals	4		20000	100.
			311487	172831	55.4
	Total Weight =		484318"		

Approximate Cost of Bridge f.o.b. cars Chicago @ 3½¢ per lb = .035 × 484318 = \$16950.

DEAD LOAD STRESS DIAGRAM.



DEAD LOAD Per PANEL Per TRUSS.
12000# " " Bottom Chord.
20000# " " Top " .

LIVE LOAD STRESSES
FROM
EQUAL JOINT LOADS.

Reactions

(a) For Full Load

$$V_1 = 4 \times 80.5 = 322.$$

$$H = \frac{4 \times 80.5 \times 57.5}{93} = 398.17$$

(b) Load from U_2 to right end.

$$V_1 = \frac{28}{9} \times 80.5 = 250.44$$

$$H = \frac{4 \times 80.5 \times 57.5 + 3 \times 80.5 \times 69}{93} = 378.26$$

(c) Load from U_3 to right end

$$V_1 = \frac{21}{9} \times 80.5 = 187.83$$

$$H = \frac{4 \times 80.5 \times 57.5 + 2 \times 80.5 \times 80.5}{93} = 338.44$$

(d) Load from U_4 to right end

$$V_1 = \frac{15}{9} \times 80.5 = 134.16$$

$$H = \frac{4 \times 80.5 \times 57.5 + 80.5 \times 92}{93} = 278.72$$

(e) Load from U_5 to right end.

$$V_1 = \frac{10}{9} \times 80.5 = 89.44$$

$$H = \frac{4 \times 80.5 \times 57.5}{93} = 378.26$$

(f) Load at U_1.

$$V_1 = 8/9 \times 80.5 = 71.55$$

$$H = \frac{80.5 \times 23}{93} = 19.9$$

(g) Loads at U_1 & U_2.

$$V_1 = \frac{15}{9} \times 80.5 = 134.16$$

$$H = \frac{2 \times 80.5 \times 34.5}{93} = 59.72$$

(h) Loads at U_1 U_2 & U_3.

$$V_1 = \frac{21}{9} \times 80.5 = 187.83$$

$$H = \frac{3 \times 80.5 \times 46}{93} = 119.45$$

(i) Loads at U_1 U_2 U_3 & U_4.

$$V_1 = \frac{26}{9} \times 80.5 = 232.55$$

$$H = \frac{4 \times 80.5 \times 57.5}{93} = 378.26$$

(j) Loads at U_2 U_3 & U_4.

$$V_1 = \frac{18}{9} \times 80.5 = 161$$

$$H = \frac{3 \times 80.5 \times 69}{93} = 179.18$$

(k) Loads at U_3 & U_4.

$$V_1 = \frac{11}{9} \times 80.5 = 98.39$$

$$H = \frac{2 \times 80.5 \times 80.5}{93} = 140.87$$

(l) Load at U_1 U_2 U_3 U_5 U_6 U_7 & U_8

$$V_1 = \frac{31}{9} \times 80.5 = 277.27$$

$$H = \frac{3 \times 80.5 \times 46 + 4 \times 80.5 \times 57.5}{93} = 318.5$$

(g) Loads at U_4 U_5 U_6 U_7 U_8.

$$V_1 = \frac{18}{9} \times 80.5 = 161$$

$$H = \frac{4 \times 80.5 \times 57.5 + 80.5 \times 23}{93} = 219$$

Upper Chord Stresses.

The max stress occurs when the left half of the bridge is loaded, and the min stress when the right half is loaded.

$U_0 U_1$ (See page 9 for reactions).

$$\text{Max stress} = \frac{232.55 \times 23 - 199.08 \times 12.34}{39.66} = +72.92$$

$$\text{Min} \;\;..\;\; = \frac{89.44 \times 23 - 199.08 \times 12.34}{39.66} = -10.07$$

$U_1 U_2$ Moments about L_2

$$\text{Max stress} = \frac{232.55 \times 46 - 199.08 \times 24 - 80.5 \times 23}{28}$$

$$= +145$$

$$\text{Min stress} = \frac{89.44 \times 46 - 199.08 \times 24}{28}$$

$$= -23.7$$

$U_2 U_3$ Moments about L_3

$$\text{Max stress} = \frac{232.55 \times 69 - 199.08 \times 34.25 - 2 \times 80.5 \times 34.5}{17.75}$$

$$= +206.92$$

$$\text{Min stress} = \frac{89.44 \times 69 - 199.08 \times 34.25}{17.75}$$

$$= -36.45$$

$U_3 U_4$ Moments about L_4.

Max stress = +206.92. $U_3 L_4$ is not acting hence $U_3 U_4$ has the same stress as $U_2 U_3$

Min stress = 0

$U_4 U_{4\frac{1}{2}}$ Stress same as $L_4 L_{4\frac{1}{2}}$, and max for full load

$$\text{Stress} = \frac{398.17 \times 41 + 4 \times 80.5 \times 57.5 - 322 \times 115}{9.92}$$

$$= +221.47$$

Lower Chord Stresses.

L_0L_1 Moments about U_0

Stress max. for full load.

Max stress = $\dfrac{398.17 \times 52}{45.83} = +451.8$

L_1L_2 Moments about U_1

Truss loaded from U_2 to right end for max stress.

Max stress = $\dfrac{378.26 \times 52 - 250.44 \times 23}{35.37} = +393.25$

One load (U_1) for min. stress.

Min stress = $\dfrac{52 \times 19.9 - 23 \times 71.55}{35.37} = -17.23$

L_2L_3 Moments about U_2

Truss loaded from U_3 to right end for max. stress.

Max stress = $\dfrac{338.44 \times 52 - 187.83 \times 46}{25.58} = +350.22$

Loads at U_1 and U_2 for min stress

Min stress = $\dfrac{59.72 \times 52 - 134.16 \times 46 + 80.5 \times 23}{25.58}$

$= -47.47$

L_3L_4 Moments about U_3

Truss loaded from U_4 to right end for max stress.

Max stress = $\dfrac{278.72 \times 52 - 134.16 \times 69}{17.03} = +307.48$

Loads at U_1, U_2 and U_3 for min stress.

Min stress = $\dfrac{119.45 \times 52 + 2 \times 80.5 \times 34.5 - 187.83 \times 69}{17.03}$

$= -70.13$

$L_4L_{4\frac{1}{2}}$. Stress same as $U_4U_{4\frac{1}{2}}$. (see page 11)

Web Stresses.

U_0L_0 Arm of stress $= \frac{52 \times 23}{12.34} = 96.9'$

Max stress occurs for full load.

Max stress $= 341.92 - \frac{199.08 \times 52}{96.9} = +235.09$

Min stress occurs when right half of truss is loaded.

Min stress $= \frac{89.44 \times 96.9 - 199.08 \times 52}{96.9} = -17.4$

U_1L_1 Arm of stress $= \frac{39.66 \times 22}{11.66} = 78.23$

" " $V_1 = 101.23$

Max stress occurs when left half of bridge is loaded.

Max stress $= \frac{232.55 \times 101.23 - 199.08 \times 52}{78.23} = +168.5$

Min stress occurs when right half of bridge is loaded

Min. stress $= \frac{89.4 \times 101.23 - 199. \times 52}{78.23} = -16.59$

U_2L_2 Arm of stress $= \frac{28 \times 23}{10.25} = 62.82$

" " $V_1 = 46 + 62.82 = 108.82$

Max stress occurs with loads at U_2 U_3 and U_4.

Max stress $= \frac{161 \times 108.82 - 179.18 \times 52}{62.82} = +130.6$

Min stress occurs with loads at U_1 U_5 U_6 U_7 & U_8.

Min stress $= \frac{161 \times 108.82 - 219.52 \times 52 - 80.5 \times 85.8}{62.8}$

$= -12.39$

U_3L_3 Arm of stress $= \frac{17.75 \times 23}{6.75} = 60$

" " $V_1 = 129.48$

Stress is max for loads at U_3 U_4 U_5 U_6 U_7 & U_8.

$U_3 L_3$

Max stress $= \dfrac{187.83 \times 129.4 - 338.4 \times 52}{60.4}$

$= +111.06$

$U_4 L_4$ Load from U_2 to right end of bridge.

The stress will be obtained by resolution.

Stress = load at U_4 − vertical component of $U_4 U_{4\frac{1}{2}}$ + vertical component of $L_3 U_4$

Arm of $L_3 U_4 = 22.89'$

Stress in $L_3 U_4 = \dfrac{250.44 \times 129.48 - 378.26 \times 52 - 3 \times 80.5 \times 60.48}{22.89}$

$= -80.7$

Vertical component $= \dfrac{80.7 \times 17.75}{29.05} = 49.3$

Arm of $U_4 U_{4\frac{1}{2}} = 9.92'$ (Moments about L_4)

Stress $= \dfrac{250.44 \times 92 - 378.26 \times 41 - 2 \times 80.5 \times 34.5}{9.92}$

$= +199.3$

Vertical component $= \dfrac{199.3 \times 5.5}{12.74} = 86$

Max stress in $U_4 L_4 = 80.5 + 49.3 - 86 = +43.8$

For min stress all joints are loaded except U_4

Stress in $L_3 U_4 = \dfrac{277.27 \times 129.48 - 318.5 \times 52 - 3 \times 80.5 \times 84.48}{22.89}$

$= -35.8$

Vertical component $= \dfrac{35.8 \times 17.75}{29.05} = 21.8$

Stress in $U_4 U_{4\frac{1}{2}} = \dfrac{277.27 \times 92 - 318.5 \times 41 - 3 \times 80.5 \times 46}{9.92}$

$= +135.21$

Vertical component $= \dfrac{135.21 \times 5.5}{12.74} = -58.3$

Min. stress in $U_4 L_4 = 21.8 - 58.3 = -36.5$

U_0L_1 Max Compression occurs when right half of bridge is loaded.

$$\text{Arm of stress} = \frac{76.9 \times 23}{45.85} = 38.8'$$

$$\text{〃 〃 } V_1 = 96.9'$$

$$\text{Stress} = \frac{199.08 \times 52 - 89.44 \times 96.9}{83.81} = +20.1$$

Max tension occurs when left half of bridge is loaded.

$$\text{Stress} = \frac{199.08 \times 52 - 232.55 \times 96.9}{83.81} = -145.35$$

U_1L_2 Max compression occurs with loads at U_1 U_5, U_6 U_7 & U_8.

$$\text{Arm of stress} = \frac{78.23 \times 28}{36.24} = 60.44'$$

$$\text{〃 〃 } V_1 = 78.23 + 23 = 101.23'$$

$$\text{Stress} = \frac{219 \times 52 + 80.5 \times 78.23 - 161 \times 101.23}{60.44}$$

$$= +22.39$$

Max tension occurs with loads at U_1 U_2 U_3.

$$\text{Stress} = \frac{179.1 \times 52 - 161 \times 101.23}{60.44} = -115.65$$

U_2L_3 Max. compression occurs with loads at U_1 U_2 U_5 U_6 U_7 & U_8.

$$\text{Arm of stress} = \frac{62.82 \times 17.75}{29.05} = 38.39'$$

$$\text{〃 〃 } V_1 = 46 + 38.39 = 108.82$$

$$\text{Stress} = \frac{258.8 \times 52 + 2 \times 80.5 \times 74.32 - 223.31 \times 108.8}{38.39}$$

$$= +28.45$$

Max tension occurs with loads at U_3 & U_4.

$$\text{Stress} = \frac{138.36 \times 52 - 98.39 \times 108.82}{38.3} = -91.5$$

L_3U_1 Max tension occurs with loads at $U_1 U_2$ & U_3.

$$\text{Stress} = \frac{187.8 \times 129.48 - 3 \times 80.5 \times 83.48 - 199.77 \times 52}{22.89}$$

$$= -90.4$$

U_3L_4 Max tension occurs with loads at $U_4\ U_5\ U_6\ U_7$ & U_8.

$$\text{Stress} = \frac{278.72 \times 52 - 134.16 \times 129.48}{26.44}$$

$$= -108.9$$

WIND STRESSES.

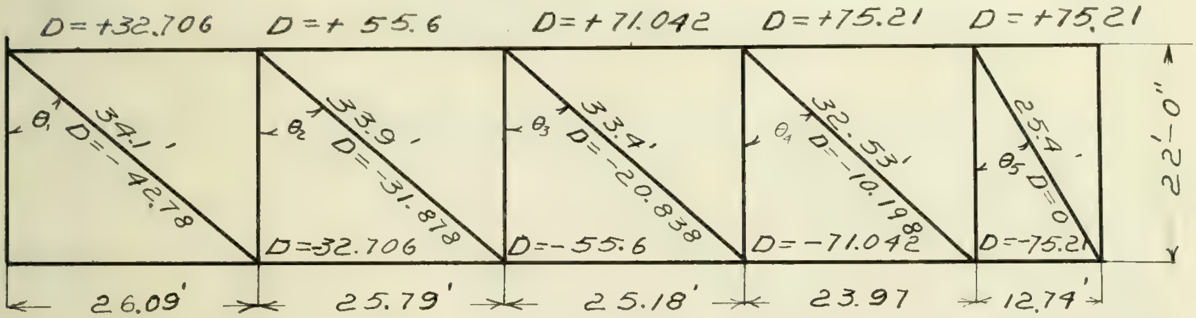
(a) Dead Wind Load. Stresses.

Panel load = .150 × 23 = 3.45

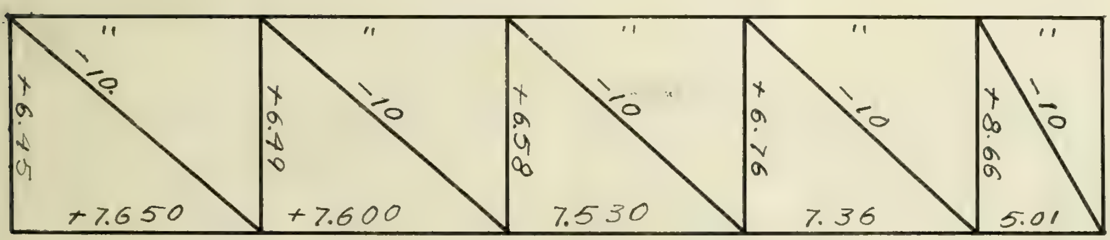
The top lateral system is not designed to take wind stress. The sway bracing transfers the wind stresses to the lower lateral system, hence the actual load at each lower chord point = 2 × 3.45 = 6.9

R_1 = 4 × 6.9 = 27.6

Lower Lateral System Developed.



Initial tension Stresses.



$\tan \theta_1 = 1.185$ $\sec \theta_1 = 1.55$

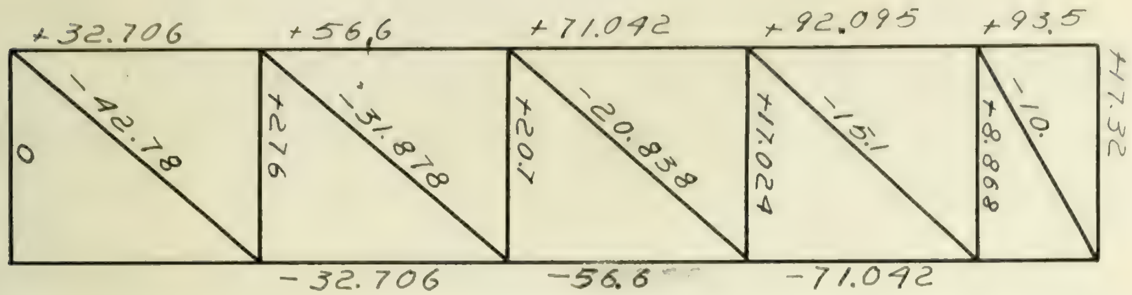
$\tan \theta_2 = 1.172$ $\sec \theta_2 = 1.54$

$\tan \theta_3 = 1.144$ $\sec \theta_3 = 1.52$

$\tan \theta_4 = 1.09$ $\sec \theta_4 = 1.48$

$\tan \theta_5 = .55$ $\sec \theta_5 = 1.15$

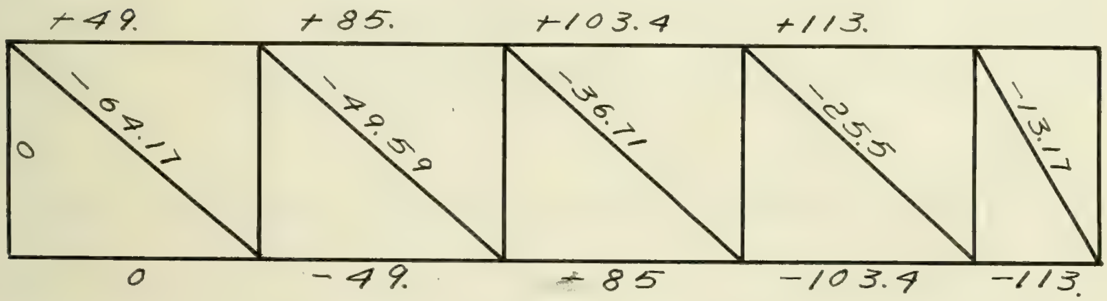
Stresses due to Dead Wind Load and Initial Tension.



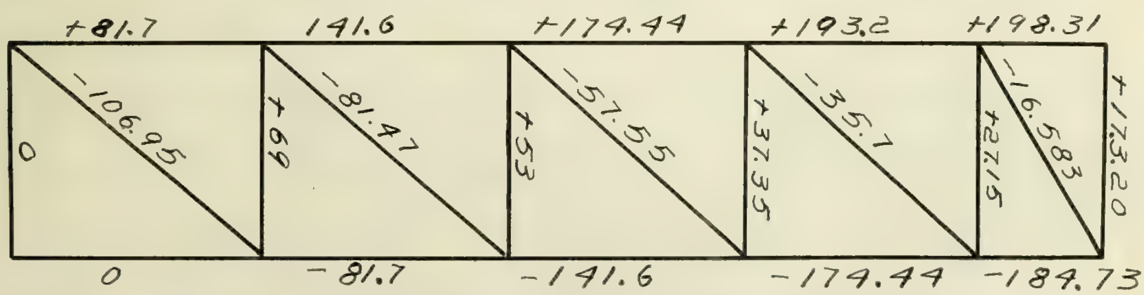
Live Wind Panel Load = 23 × .450 = 10.35

R = 4 × 10.35 = 41.4

(b) Live Wind Load Stresses,



Stresses due to Live and Dead Wind Loads, and Initial Tension.



WIND STRESSES
IN TRUSS.

Dead Wind Stresses.

Horizontal wind load at each panel point of upper and lower chord $= 23 \times .150$
$= 3.45$

Vertical wind loads and increments considered as acting at upper panel points. The panel loads are as follows.

at U_4 — $\frac{3.45 \times 11}{22} = 1.725$

" U_3 — $\frac{3.45 \times 17.75}{22} + \frac{2 \times 3.45 \times 6.75}{22} = 4.9$

" U_2 — $\frac{3.15 \times 22.8}{22} + \frac{4 \times 3.45 \times 10.25}{22} = 10.818$

" U_1 — $\frac{3.45 \times 39.66}{22} + \frac{6 \times 3.45 \times 11.66}{22} = 17.187$

" U_0 — $\frac{(19.75 + 11.5) \times 150 \times 52}{22} + \frac{8 \times 3.45 \times 12.34}{22} = 26.555$

The load at U_0 will be omitted in getting V_1 and H since it produces no stress in members beyond $U_0 L_0$

$V_1 = 1.725 + 4.9 + 10.818 + 17.187 = 34.63$

$H = 2 \times \frac{92 \times 1.725 + 69 \times 4.9 + 46 \times 10.818 + 23 \times 17.187}{93}$

$= 29.88$

With the loads and reactions determined as above, the dead load wind stresses may be found in the same manner as the live load stress. (See pages 8 to 16)

(a) Upper Chord Stresses.

$U_0 U_1$ Moments about L_1

$$\text{Stress} = \frac{34.63 \times 23 - 29.88 \times 12.34}{39.66} = +10.78$$

$U_1 U_2$ Moments about L_2

$$\text{Stress} = \frac{34.63 \times 46 - 29.88 \times 24 - 17.187 \times 23}{28} = +17.16$$

$U_2 U_3$ Moments about L_3

$$\text{Stress} = \frac{34.63 \times 69 - 29.88 \times 34.25 - 17.187 \times 46 - 10.12 \times 23}{17.75}$$

$$= +18.4$$

$U_3 U_4$ Moments about L_3

There is no stress in $U_3 L_4$ for this loading therefore the stress is the same as in $U_2 U_3$

$U_4 U_{4\frac{1}{2}}$ Moments about L_4

$$\text{Stress} = \frac{164.65}{9.92} = +16.59$$

(b) Lower Chord Stresses.

$L_1 L_2$ Moments about U_1

$$\text{Stress} = \frac{29.88 \times 52 - 34.63 \times 23}{35.37} = +21.41$$

$L_2 L_3$ Moments about U_2

$$\text{Stress} = \frac{29.88 \times 52 + 17.187 \times 23 - 34.63 \times 46}{25.575} = +13.9$$

$L_3 L_4$ Moments about U_4

$$\text{Stress} = \frac{29.88 \times 52 + 17.187 \times 69 + 10.818 \times 46 + 4.9 \times 23 - 34.63 \times 92}{10.55}$$

$$= +15.54$$

$L_4 L_{4\frac{1}{2}}$ See $U_4 U_{4\frac{1}{2}}$ page 20

(c) Web Stresses.

$U_0 L_1$ Arm of stress = 83.81′ (see page 15)

" " V_1 = 96.9′ (" " 15)

$$\text{Stress} = \frac{29.88 \times 52 - 34.63 \times 96.9}{83.81} = -21.49$$

$U_1 L_1$ Arm of stress = 78.23 (see page 13)

" " V_1 = 101.23 (" " 13)

$$\text{Stress} = \frac{34.63 \times 101.23 - 29.88 \times 52}{78.23} = +24.9$$

$U_1 L_2$ Arm of stress = 60.44 (see page 15)

" " V_1 = 101.23 (" " 15)

$$\text{Stress} = \frac{29.88 \times 52 + 17.187 \times 78.23 - 34.63 \times 101.23}{60.44}$$

$$= -10.04$$

$U_2 L_2$ Arm of stress = 62.82 (see page 13)

" " V_1 = 108.82 (" " 13)

$$\text{Stress} = \frac{34.63 \times 108.82 - 29.88 \times 52 - 17.187 \times 85.82}{62.82}$$

$$= +11.7$$

$U_2 L_3$ Arm of stress = 38.3

" " V_1 = 108.82

$$\text{Stress} = \frac{29.88 \times 52 + 17.187 \times 85.82 + 10.818 \times 62.82 - 34.63 \times 108.82}{38.3}$$

$$= -.002$$

$U_3 L_3$ There is no stress in $U_3 L_4$, therefore the stress in $U_3 L_3$ equals the load at U_3 $= +4.9$

L_3U_4 Arm of stress = 22.9'

$\therefore \quad V_1 = 129.48$

$$\text{Stress} = \frac{34.63 \times 129.48 - 29.88 \times 52 - 17.187 \times 106.48 - 10.818 \times 83.48 - 4.9 \times 60.48}{22.9}$$

$= -4.51$

U_4L_4 The stress in this member is the same as the sum of the vertical components of the stresses in L_3U_4 and $U_4U_{4\frac{1}{2}}$ plus the load at U_4.

Vertical component of stress in L_3U_4

$$= \frac{3.16 \times 17.75}{29.05} = +1.931$$

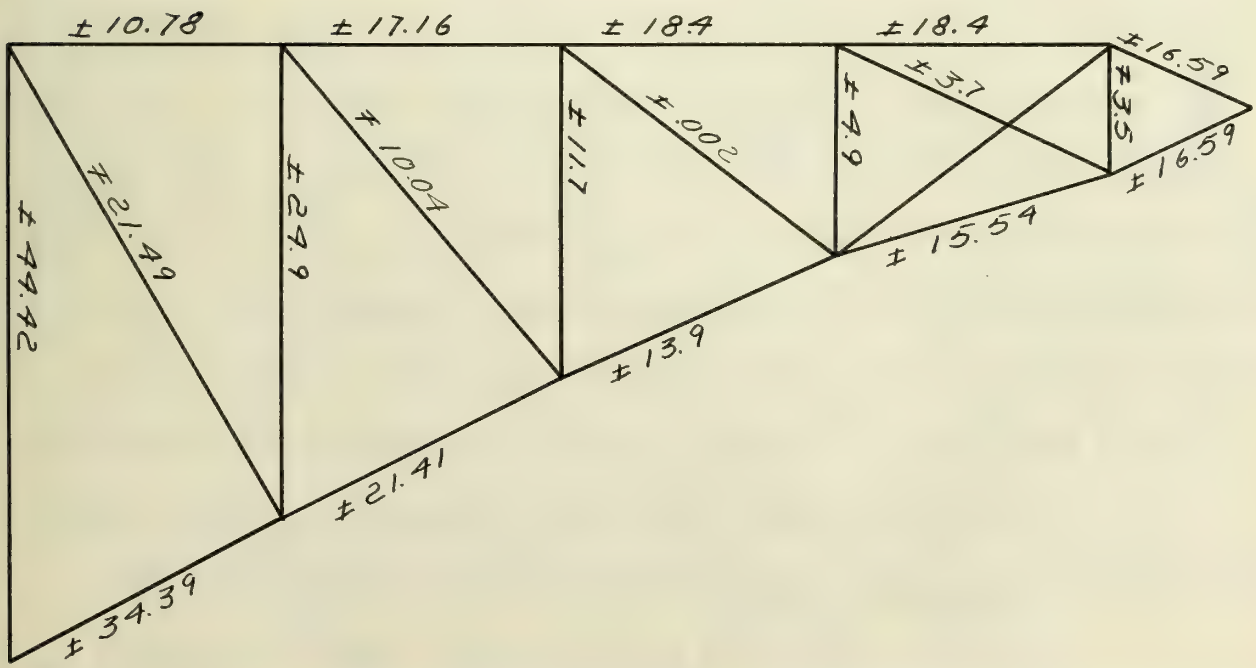
Vertical component of stress in $U_4U_{4\frac{1}{2}}$

$$= \frac{16.59 \times 5.5}{12.74} = -7.162$$

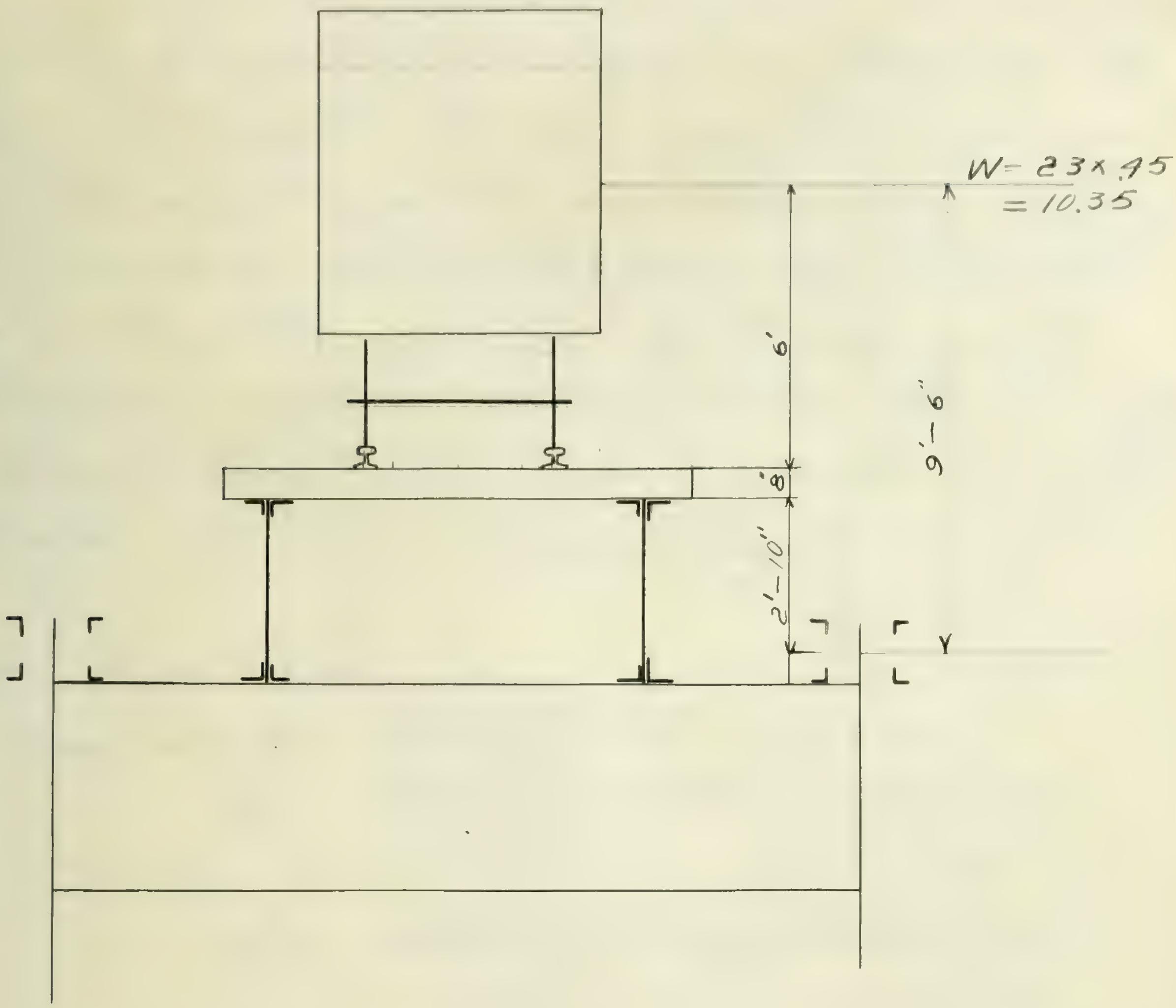
Load at $U_4 = +1.725$

Stress in $U_4L_4 = 1.931 + 1.725 - 7.162 = -3.5$

DEAD WIND LOAD STRESSES.



LIVE WIND LOAD STRESSES.



The load will be considered as coming on the bridge from the left, and passing off the right end of the bridge. The bridge will be considered as loaded continuously from the joint considered to the right end.

The live wind load acts at a point 9.5' above the center line of the top chord. (See above figure, and Cooper, page 6).

The horizontal load per panel is 23 × 450# = 10350# (See Cooper, page 6.)

Panel Loads and Reactions.

In the computations below, the lever arms of the forces will be used in terms of the panel length. The horizontal component of the right reaction is obtained by taking moments about the point of intersection of a line through the left and center hinges, with a vertical through the right hinge. That point is 93' above the right hinge. 93' = 4.04 × panel length.

(a) Full Load.

$$\text{Load at } U_4 = \frac{10.35\times(9.5+11)}{22} = 9.644$$

$$\text{" " } U_3 = \frac{10.35(9.5+17.75)}{22} + \frac{10.35\times 6.75}{22}$$

$$= 12.82 + 3.175 = 16.$$

$$\text{" " } U_2 = \frac{10.35(9.5+28)+2\times 10.35\times 10.25}{22}$$

$$= 17.642 + 9.644 = 27.286$$

$$\text{" " } U_1 = \frac{10.35(9.5+39.66)+3\times 10.35\times 11.66}{22}$$

$$= 23.12 + 16.45 = 39.584$$

$$\text{" " } U_0 = \frac{14.175(9.5+52)+4\times 10.35\times 12.34}{22}$$

$$= 39.62 + 23.22 = 62.841$$

The load at U_0 will be omitted in obtaining the reactions.

$V_1 = V_2 =$ sum of the loads $= 92.514$

$$H_1 = H_2 = 2\times\frac{4\times 9.644+3\times 16+2\times 27.28+39.58}{4.04} = 89.4$$

(b) Load from U_2 to right end.

$$V_1 = 16.45 + 27.28 + 16 + 9.64 + \tfrac{1}{9} \times 39.57 = 73.77$$

$$H = \frac{(39.57 + 16.45) + 2(27.28 + 27.28) + 3(16 + 16) + 4(9.64 + 9.64)}{4.04}$$

$$= 83.78$$

(c) Load from U_3 to right end.

$$\text{Increment of loads at } U_1 = 2\tfrac{1}{7} \times \frac{10.35 \times 11.65}{22}$$

$$= 11.752$$

$$\text{Increment of loads at } U_8 = 2\tfrac{6}{7} \times \frac{10.35 \times 11.66}{22}$$

$$= 15.66$$

$$V_1 = 9.644 + 16 + \frac{7 \times 9.64 + 2 \times 26.92 + 8 \times 11.75 + 39.58}{9}$$

$$= 25.64 + 28.23 = 53.87$$

$$H = \frac{11.75 + 38.78) + 2(9.64 + 26.92) + 3(16 + 16) + 4(9.44 + 9.44)}{4.04}$$

$$= 73.46$$

(d) Load from U_4 to right end.

$$\text{Increment of loads at } U_2 = 1\tfrac{1}{5} \times \frac{10.25 \times 10.35}{22} = 5.78$$

$$\text{" " " " } U_7 = 1\tfrac{4}{5} \times \text{ " } = 8.67$$

$$\text{" " " " } U_1 = 1\tfrac{3}{7} \times \frac{11.66 \times 10.35}{22} = 7.84$$

$$\text{" " " " } U_8 = 2\tfrac{4}{7} \times \text{ " } = 14.41$$

$$V_1 = \frac{8 \times 7.84 + 7 \times 5.78 + 6 \times 3.175 + 5 \times 9.644 + 4 \times 9.644 + 3 \times 16 + 2 \times 26.31 + 37.22}{9}$$

$$= 38.54$$

$$H = \frac{(7.84 + 37.22) + 2(5.78 + 26.31) + 3(3.178 + 16) + 8 \times 9.644}{4.04}$$

$$= 60.37$$

(e) Load on right half of Bridge.

$$\text{Increment of loads at } U_4 = 0$$

$$\text{" " " " } U_3 = \tfrac{1}{3} \times \frac{6.25 \times 10.35}{22} = .98$$

$$\text{" " " " } U_2 = \left(\tfrac{2}{5} + \tfrac{1}{5}\right) \times \frac{10.25 \times 10.35}{22} = 2.89$$

Increment of loads at $U_1 = \left(\frac{3}{7} + \frac{2}{7} + \frac{1}{7}\right) \times \frac{11.66 \times 10.35}{22}$

" " " $= 4.7$

" " " $U_6 = \frac{2}{3} \times 2.94 = 1.96$

" " " $U_7 = \frac{7}{5} \times 4.82 = 6.748$

" " " $U_8 = \frac{15}{7} \times 5.48 = 11.74$

$$V_1 = \frac{8 \times 4.7 + 7 \times 2.89 + 6 \times .98 + 4 \times 9.64 + 3 \times 14.78 + 2 \times 24.03 + 34.8}{9}$$

$= 25.5$

$$H = \frac{(4.7 + 34.86) + 2(2.89 + 24.03) + 3(.98 + 14.78) + 4 \times 9.64}{4.04}$$

$= 44.3$

(f) Loads at U_6 U_7 and U_8

Increment of loads at $U_1 = \frac{3}{7} \times 5.48 = 2.34$

" " " " $U_2 = \frac{1}{5} \times 4.82 = .964$

" " " " $U_7 = \frac{4}{5} \times \frac{10.25 \times 10.35}{22} = 3.85$

" " " " $U_8 = \left(\frac{5}{7} + \frac{6}{7}\right) \times \frac{11.66 \times 10.35}{22} = 8.61$

$$V_1 = \frac{8 \times 2.34 + 7 \times .96 + 3 \times 12.82 + 2 \times 21.14 + 31.73}{9}$$

$= 15.32$

$$H = \frac{(2.34 + 31.73) + 2(.96 + 21.14) + 3 \times 12.82}{4.04}$$

$= 28.89$

(g) Loads at U_7 and U_8.

Increments of loads at $U_1 = \frac{1}{7} \times \frac{11.66 \times 10.35}{22} = .78$

" " " " $U_8 = \frac{6}{7} \times 5.48 = 4.68$

$$V_1 = \frac{8 \times .78 + 2 \times 17.28 + 23.12}{9} = 7.1$$

$$H = \frac{2 \times 17.28 + (.78 + 4.68)}{4.04} = 9.9$$

(h) Load at U_8

$V_1 = \frac{1}{9} \times 23.12$ $\qquad V_2 = \frac{8}{9} \times 23.12 = 20.56$

$$H = \frac{23.12}{4.04} = 5.7$$

MAXIMUM STRESSES

(a) Upper Chord

U_0U_1 – Max stress for load on left half.

$V_1 = 66.38$, $H = 44.3$ (See page 26)

Arm of stress = 39.66

" " V_1 = 23

" " H = 12.3'

Moments about L_1

$$\text{Stress} = \frac{66.38 \times 23 - 44.3 \times 12.34}{39.66} = \pm 24.71$$

U_1U_2 Arm of stress = 28'

Moments about L_2

$$\text{Stress} = \frac{66.38 \times 46 - 44.3 \times 24 - 34.86 \times 23}{28}$$

$= \pm 42.44$

U_2U_3 Arm of stress = 17.75

Moments about L_3

$$\text{Stress} = \frac{66.38 \times 69 - 44.3 \times 34.25 - 34.86 \times 46 - 24.03 \times 23}{17.75}$$

$= \pm 49.72$

U_3U_4 Arm of stress = 11'

Moments about L_4. [-14.78×23

$$\text{Stress} = \frac{66.38 \times 92 - 44.3 \times 41 - 34.86 \times 69 - 24.03 \times 46}{11}$$

$= \pm 40$

$U_4U_{4\frac{1}{2}}$ – Max stress for load from U_2 to right end.

$V_1 = 73.77$, $H = 83.78$. (See page 25.)

Arm of stress = 9.92' (See page 11).

Arm of V_1 = 92'

Moments about L_4

$$\text{Stress} = \frac{73.77 \times 92 - 83.78 - 16.45 \times 69 - 27.28 \times 46 - 16 \times 23}{9.92}$$
$$= \pm 59.8$$

(b) Lower Chord.

L_0L_1 Stress max for full load.
Moments about U_0

$V_1 = 92.51 \quad H = 89.41$

$$\text{Stress} = \frac{89.41 \times 52}{45.827} = \pm 110.04$$

L_1L_2 Load from U_2 to right end.
Moments about U_1

$V_1 = 73.77 \quad H = 83.78$

$$\text{Stress} = \frac{83.78 \times 52 - 73.77 \times 23}{35.369} = \pm 75.2$$

L_2L_3 Load from U_3 to right end.
Moments about U_2

$V_1 = 53.87 \quad H = 73.46$

$$\text{Stress} = \frac{73.46 \times 52 - 53.87 \times 46 + 11.75 \times 23}{25.575} = \pm 63.3$$

L_3L_4 Load from U_4 to right end.
Moments about U_3

$V_1 = 28.54 \quad H = 60.37$

$$\text{Stress} = \frac{60.37 \times 52 - 38.54 \times 69 + 7.89 \times 46}{17.031} = \pm 57.1$$

$L_4L_{4\frac{1}{2}}$ Stress the same as in $U_4U_{4\frac{1}{2}}$ (See page 27.)

(c) Web Stresses.

U_0L_1 Stress max for left half loaded.

Arm of stress $= 83.81$

" " $V_1 = 89.44$

$V_1 = 66.38 \quad H = 44.3$

$$\text{Stress} = \frac{44.3 \times 52 - 66.38 \times 101.23}{83.81} = \mp 52.7$$

U_1L_2 Load from U_2 to right end.

Arm of stress $= 60.44$

" " $V_1 = 101.23$

$V_1 = 73.77 \quad H = 83.78$

$$\text{Stress} = \frac{83.78 \times 52 + 16.45 \times 78.23 - 73.77 \times 101.23}{60.44}$$

$= \mp 30.18$

U_2L_3 Load from U_3 to right end.

Arm of stress $= 38.3$

" " $V_1 = 108.82$

$V_1 = 53.87 \quad H = 73.46$

$$\text{Stress} = \frac{73.46 \times 52 + 11.75 \times 85.82 + 9.64 \times 62.82 \; [- 53.87 \times 108.82}{38.3}$$

$= \mp 11.18$

U_3L_4 Loads at U_1 U_2 and U_3

Arm of stress $= 26.44$

" " $V_1 = 129.48$

$V_1 = 52.71 \quad H = 28.89$

$$\text{Stress} = \frac{28.89 \times 52 + 31.73 \times 106.48 + 21.14 \times 83.48 + 12.82 \times 60.48 - 52.71 \times 129.48}{26.44}$$

$= \pm 22.5$

L_3U_4 Loads at U_1 U_2 and U_3, as above

Arm of stress = 22.9

" " V_1 = 129.48

$V_1 = 52.71 \quad H = 28.89$

$$\text{Stress} = \frac{52.71 \times 129.48 - 28.89 \times 52 - 31.73 \times 106.48 - 21.14 \times 83.48 - 12.829 \times 60.48}{22.9}$$

$= \mp 26.04$

U_0L_0 Stress max. for full load.

Arm of stress = 23'

" " V_1 = 23

" " H = 12.34

$V_1 = 155.355$ (Considering load at U_0)

$H = 89.4$

$$\text{Stress} = 155.35 - \frac{89.4 \times 12.34}{23} = \pm 107.39$$

U_1L_1 – Stress max. for load on left half.

Arm of stress = 78.23'

" " V_1 = 101.23'

$V_1 = 66.38 \quad H = 44.3$

$$\text{Stress} = \frac{66.38 \times 101.23 - 44.3 \times 52}{78.23} = \pm 56.4$$

U_2L_2 – Loading the same as for U_1L_1

Arm of stress = 62.82'

" " V_1 = 108.82'

$$\text{Stress} = \frac{66.38 \times 108.82 - 44.3 \times 52 - 34.86 \times 85.82}{62.82}$$

$= \pm 30.6$

U_3L_3— Load from U_3 to right end.

Arm of stress = 60.48 $\qquad H = 73.46$

" " $\quad V_1 = 129.48 \qquad V_1 = 53.87$

$$\text{Stress} = \frac{53.87 \times 129.48 - 73.46 \times 52 - 11.75 \times 106.48 - 9.64 \times 83.48}{60.48}$$

$= \pm 18.17$

U_4L_4— Loads from U_2 to right end.

Arm of $L_3U_4 = 22.89$

" " $\quad V_1 = 129.48'$

$V_1 = 73.77 \qquad H = 83.78$

The stress will be found from the conditions of equilibrium at U_4.

$$\text{Stress in } L_3U_4 = \frac{73.77 \times 129.48 - 83.78 \times 52 - 16.45 \times 106.48 - 27.28 \times 83.48 - 16 \times 60.48}{22.89}$$

$= -12.6$

$$\text{Vertical component} = \frac{12.6 \times 17.75}{29.05} = 7.35$$

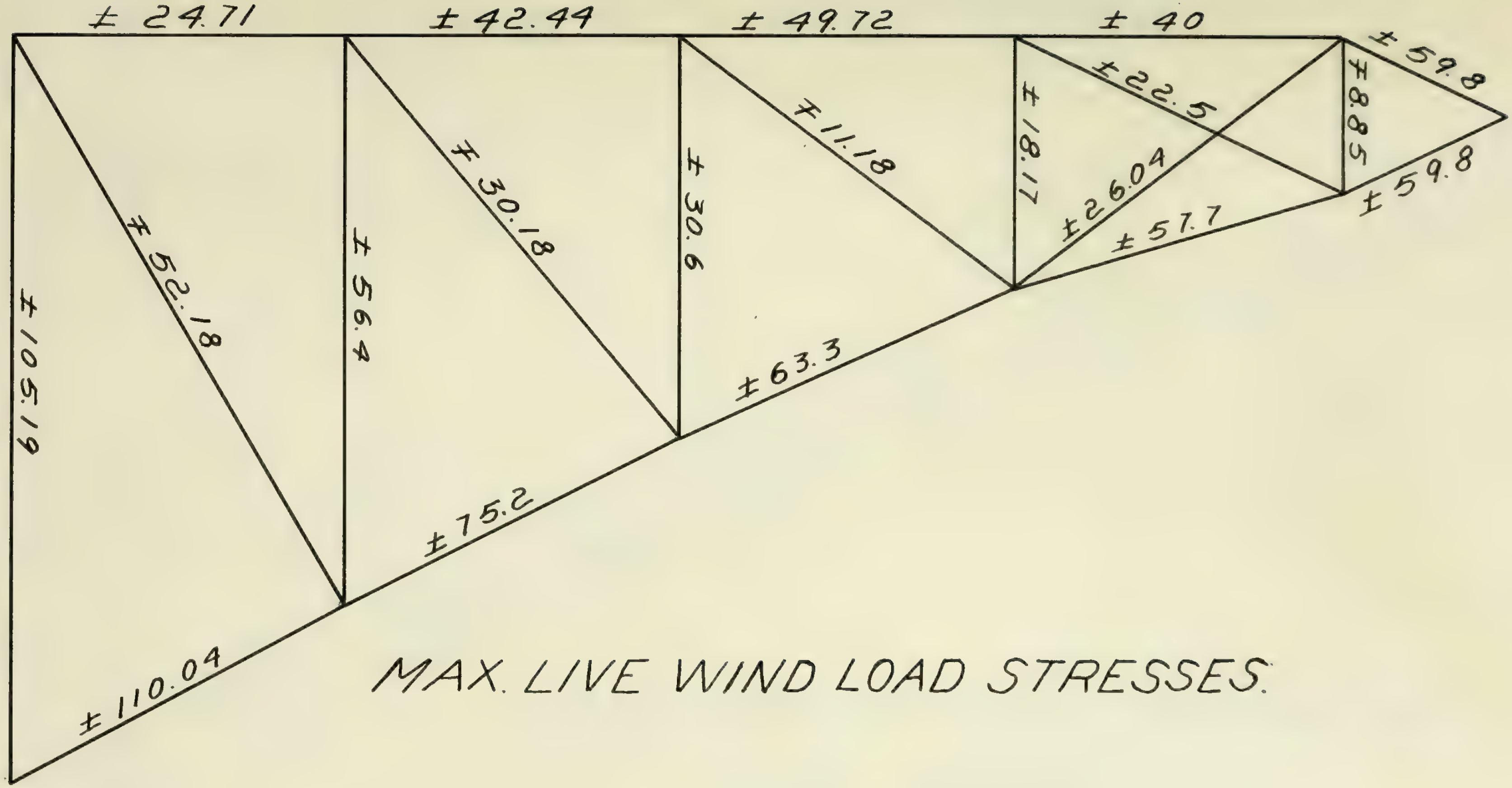
$$\text{Stress in } U_4U_{4\frac{1}{2}} = \frac{73.77 \times 92 - 83.78 \times 41 - 16.45 \times 69 - 27.28 \times 46 - 16 \times 23}{9.92}$$

$= +59.8$

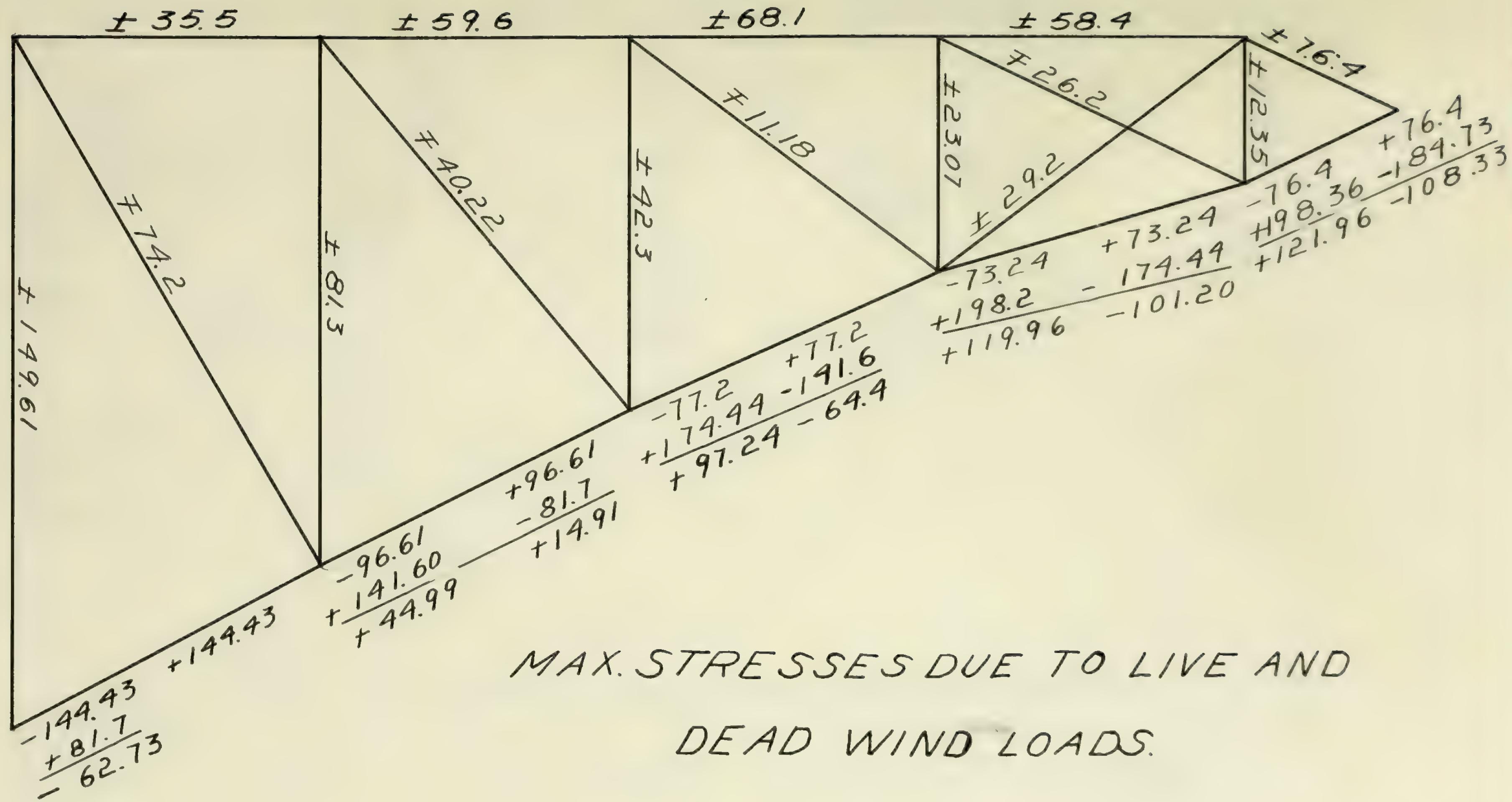
$$\text{Vertical component} = \frac{59.8 \times 5.5}{12.74} = +25.84$$

Load at $U_4 = 9.644$

Stress in $U_4L_4 = 9.644 + 7.35 - 25.84 = \mp 8.85$

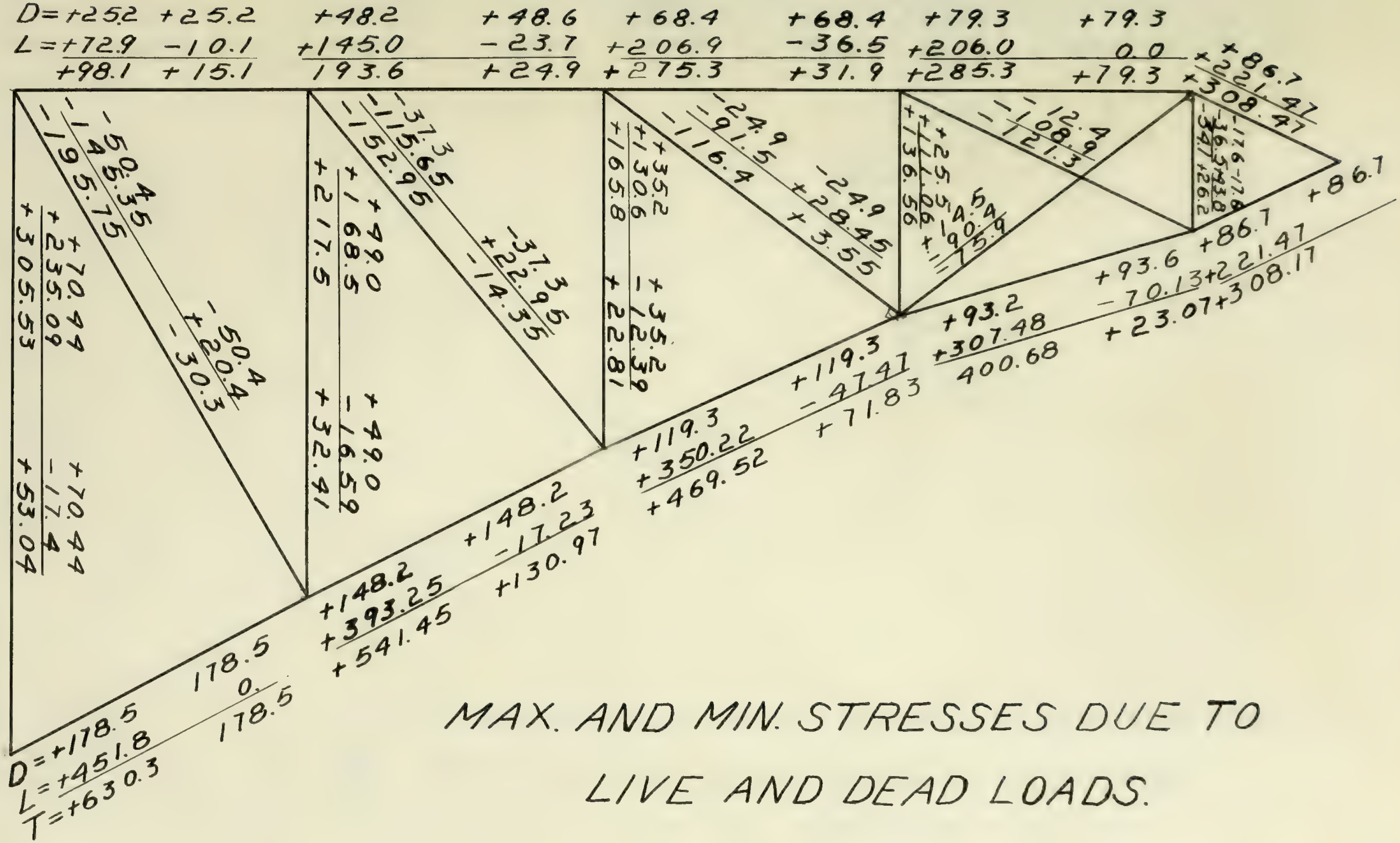


MAX. LIVE WIND LOAD STRESSES.



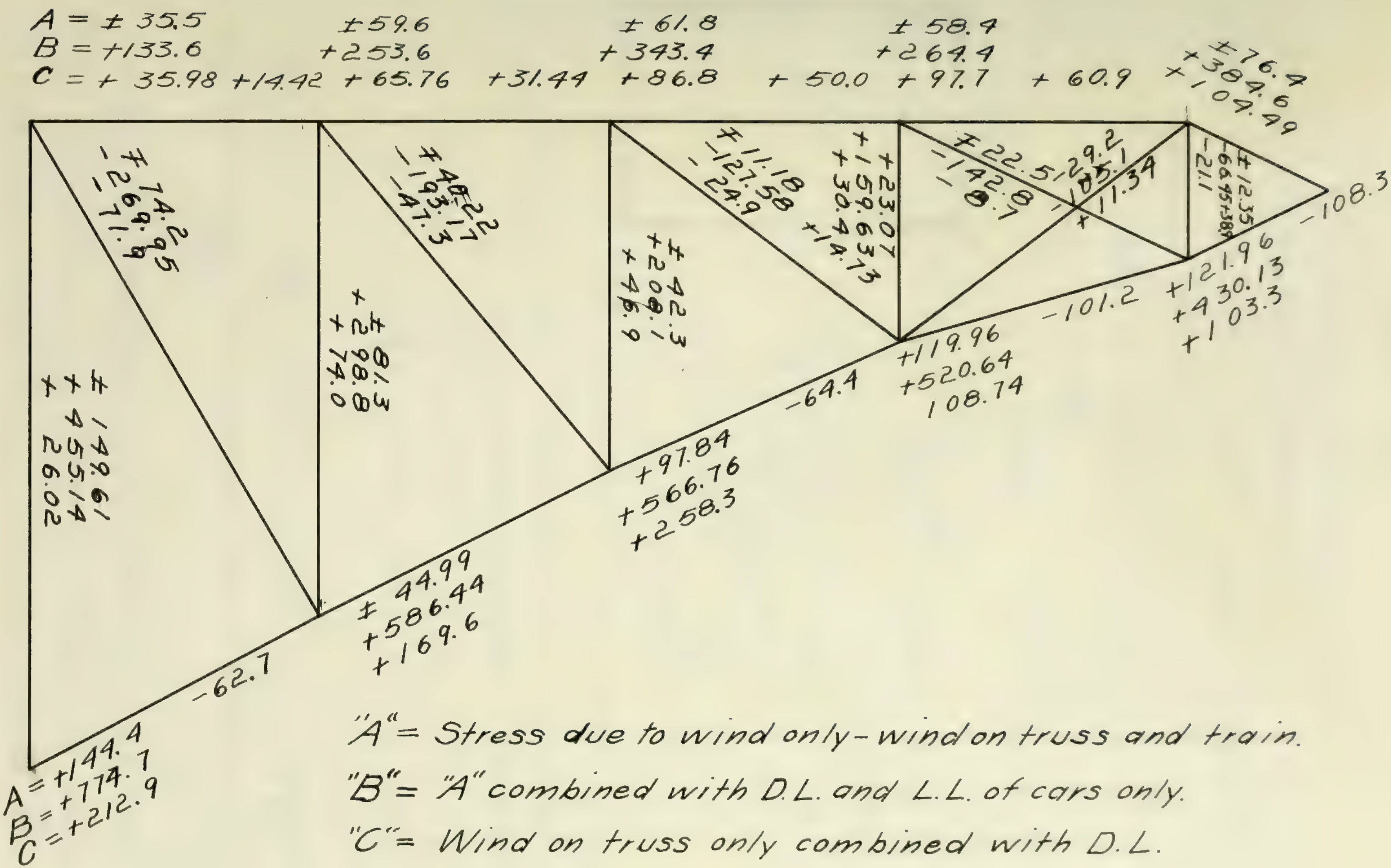
MAX. STRESSES DUE TO LIVE AND

DEAD WIND LOADS.



MAX. AND MIN. STRESSES DUE TO

LIVE AND DEAD LOADS.



"A" = Stress due to wind only - wind on truss and train.

"B" = "A" combined with D.L. and L.L. of cars only.

"C" = Wind on truss only combined with D.L.

PART 2.

Efficiency of Members.

Art 3. Compression Members.

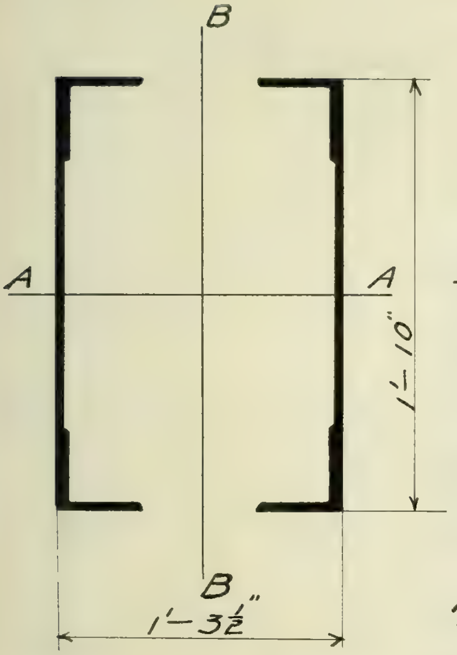
U_0L_0 — L.L. = 235530#, D.L. = 70440#

Composition

2 web Pls. $22'' \times \frac{5}{8}''$ Area = $27.5^{\square''}$

4 Ls. $4'' \times 4'' \times \frac{9}{16}''$ .. $= 16.76^{\square''}$

Total .. $= 44.22^{\square''}$



$$I_{A.A} = \frac{2 \times 5 \times 22^3}{12 \times 8} + 4(6.12 + 4.18 \times 9.79^2)$$

$$= 1109.1 + 1626.9 = 27.36$$

$$I_{B.B} = 27.5 \times 7.44^2 + 4(6.12 + 4.18 \times 5.915^2)$$

$$= 1522.2 + 609.2 = 2132$$

$$r_{B.B} = \sqrt{\frac{2132}{44.22}} = 6.1''$$

$$l = 24.5' = 294''$$

$$l \div r = 294 \div 6.1 = 48.2$$

$$P_L = 9000 - 40 \times 48.2 = 7072^{\#}$$

$$P_D = 18000 - 80 \times 48.2 = 14144^{\#}$$

$$A_L = 235090 \div 7072 = 33.24^{\square''}$$

$$A_D = 70440 \div 14144 = \underline{4.98}^{\square''}$$

$$38.22^{\square''}$$

Average allowable unit stress $= \frac{305530}{38.22} = 8000^{\#}$

Efficiency for live and dead loads $= \frac{44.22}{38.22}$

$= 115\%$

Actual unit stress $= \frac{305530}{44.22} = 6900^{\#}$

Wind stress = 149610#. This is more than 30% of the live and dead load stress.

Allowable unit stress considering wind
$= 1.30 \times 8000 = 10400^{\#}$

Total stress $= 149610^{\#} + 305530^{\#} = 455140^{\#}$

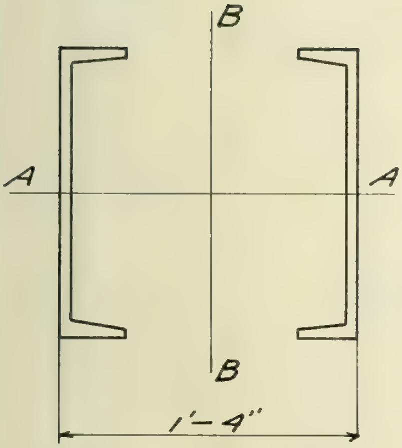
Area required considering wind $= \frac{455140}{10400}$
$= 43.7^{\square''}$

Efficiency considering wind $= \frac{44.22}{43.7} = 101\%$

U_1L_1 — L.L. $= 168500^{\#}$, D.L. $= 49000^{\#}$, W.L. $= 81300^{\#}$

Composition.

2 – 15" – 55# [s Area $= 32.36^{\square''}$



$I_{A.A.} = 2 \times 430.2 = 860.4$

$I_{B.B.} = 2(12.19 + 16.18 \times 7.18^2) = 1693$

$r_{A.A.} = \sqrt{\frac{860.4}{32.36}} = 5.16''$

$r_{B.B.} = \sqrt{\frac{1693}{32.36}} = 7.2$

$l_{A.A.} = 22.5' = 270''$

$l_{B.B.} = 34' = 408''$

$l_{A.A.} \div r_{A.A.} = 270 \div 5.16 = 52.3$

$l_{B.B.} \div r_{B.B} = 408 \div 7.2 = 56.6$

$P_L = 9000 - 40 \times 56.6 = 6736^{\#}$

$P_D = 18000 - 80 \times 56.6 = 13472^{\#}$

$A_L = 168500 \div 6736 = 25.01^{\square''}$

$A_D = 49000 \div 13472 = \underline{3.63}^{\square''}$

$28.64^{\square''}$

Average allowable unit stress for live and dead loads $= 217500 \div 28.64 = 7594^{\#}$

Actual unit stress for live and dead loads $= 217500 \div 32.36 = 6721.^{\#}$

Efficiency for live and dead loads $= \frac{32.36}{28.64} = 113\%$

The wind stress exceeds the live and dead load stress by more than 30%, so must be considered.

Allowable unit stress considering wind $= 1.30 \times 7594 = 9872^{\#}$

Total stress $= 81300^{\#} + 217500 = 298800^{\#}$

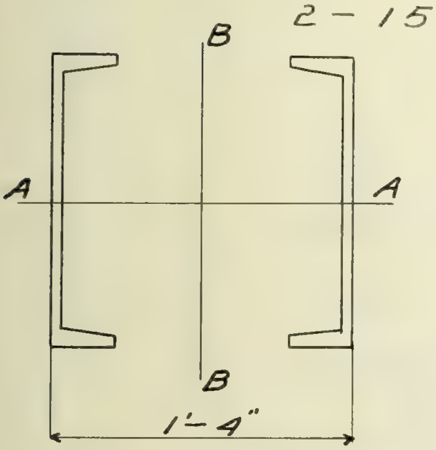
Actual unit stress $= 298800 \div 32.36 = 9261^{\#}$

Efficiency considering wind $= 9872 \div 9261 = 106\%$.

U_2L_2 — $L.L. = 130{,}600^{\#}$, $D.L. = 35{,}200^{\#}$, $W.L. = 42300^{\#}$

Composition.

$2 - 15'' - 40^{\#}$ [s. Area $= 23.5\square''$



$I_{A.A.} = 2 \times 347.5 = 695$

$r_{A.A} = \sqrt{\frac{695}{23.5}} = 5.44''$

$l_{A.A.} = 23' = 276''$

$l_{A.A.} \div r_{A.A.} = 276 \div 5.44 = 50.7$

$I_{B.B.} = 2(9.39 + 11.75 \times 7.22^2) = 1243$

$r_{B.B} = \sqrt{\frac{1243}{23.5}} = 7.2$

$P_L = 9000 - 40 \times 50.7 = 6972^{\#}$

$P_D = 18000 - 80 \times 50.7 = 13944^{\#}$

$A_L = 130600 \div 6972 = 18.73\square''$

$A_D = 35200 \div 13944 = \underline{2.52\square''}$

$21.25\square''$

Average allowable unit stress for live and dead loads $= 165800 \div 21.25 = 7800^{\#}$

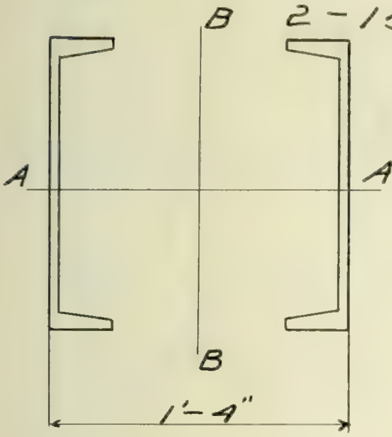
Actual unit stress $= 165{,}800 \div 23.5 = 7055^{\#}$

Efficiency for live and dead loads $= \frac{23.5}{21.25} = 110\%$
The wind stress is less than 30% of the live and dead load stress, so need not be considered.

U_3L_3 — L.L. = 111,060# D.L. = 25500# W.L. = 23070

Composition.

2 – 15" – 33# [s Area = 19.8 □"



$I_{A.A} = 2 \times 312.6 = 625.2$

$r_{A.A} = 5.62$

$l_{A.A} = 12.5' = 150''$

$l_{A.A.} \div r_{A.A.} = 150 \div 5.62 = 26.6$

$I_{B.B.} = 2(8.23 + 9.9 \times 7.21^2) = 1046$

$r_{B.B.} = \sqrt{\frac{1046}{19.8}} = 7.2$

$P_L = 9000 - 40 \times 26.6 = 7936$#

$P_D = 18000 - 80 \times 26.6 = 15872$#

$A_L = 111060 \div 7936 = 13.91$ □"

$A_D = 25500 \div 15872 = \underline{1.60}$ □

Total $= 15.51$

Average allowable unit stress for live and dead loads $= 136560 \div 15.51 = 8800$#
Actual unit stress for live and dead loads $= 136560 \div 19.8 = 6896$#
Efficiency $= 19.8 \div 15.51 = 127\%$
The wind stress is less than 30% of the live and dead load stress so need not be considered.

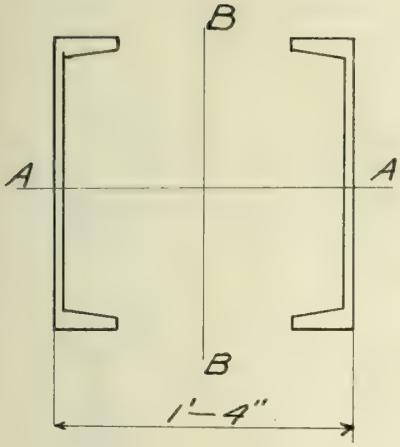
U_4L_4 — $L.L. = -36500^{\#}$, $D.L. = -17600$

$\quad " \quad = +43800$

Composition.

$2 - 15'' - 33^{\#}$ [s Area $= 19.8^{\square''}$

The moment of inertia and radius of gyration are the same as in U_3L_3



This member must be designed to take both tension and compression, both strains being increased by .8 of the least of the two strains. (Cooper par 36).

$I = 625.2, \quad r = 5.62''$

$l = 11' = 132''$

$l \div r = 132 \div 5.62 = 23.5$

(a) Efficiency in Compression.

$P_L = 9000 - 40 \times 23.5 = 8060^{\#}$

$P_D = 18000 - 80 \times 23.5 = 16120^{\#}$

Live load $= 43800^{\#} + .8 \times 36500^{\#} = 73000^{\#}$

$A_L = 73000 \div 8060 = 9.05^{\square''}$

$A_D = -17600 \div 2000 = \underline{-\ .88}^{\square''}$

$8.17^{\square''}$

Efficiency $= 19.8 \div 8.17 = 242\%$

(b) Efficiency in Tension.

$P_L = 10000^{\#} \qquad P_D = 20000^{\#}$

Live load $= -1.8 \times 36500^{\#} = -65700^{\#}$

Dead load $= -17600^{\#}$

$A_L = 65700 \div 10000 = 6.57\,\square''$

$A_D = 17600 \div 20000 = \underline{.88}\,\square''$

$7.45\,\square''$

Area of section $= 19.8\,\square''$

Deduct for 8 rivets $\underline{3.2}\,\square''$

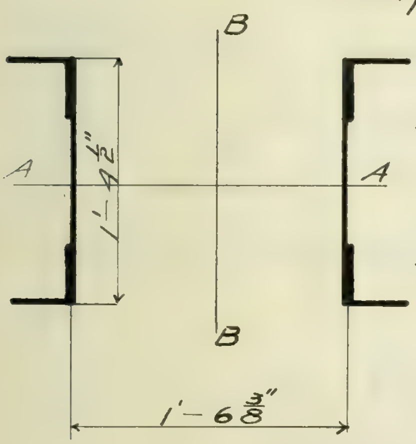
Net area $= 16.6\,\square''$

Efficiency $= 16.6 \div 7.45 = 222\%$

Upper Chord

U_0U_1 — $L.L. = 72900^{\#}$, $D.L. = 25200^{\#}$, $W.L. = 35500^{\#}$

Composition.



2 web Pls $16'' \times \frac{7}{16}''$ Area $= 14.\,\square''$

4 $\angle$s $4'' \times 4'' \times \frac{3}{8}''$ " $\underline{11.5}\,\square''$

$25.5\,\square''$

$$I_{A.A.} = 4(4.36 + 2.86 \times 7.11^2) + 2\left(\frac{7 \times 16^3}{12 \times 16}\right)$$

$$= 595.75 + 299 = 894.75$$

$$r_{A.A.} = \sqrt{\frac{894.75}{25.5}} = 5.9''$$

$$I_{B.B.} = 4(4.36 + 2.86 \times 10.33^2) + 14 \times 8.97^2$$

$$= 1249.64 + 1126.44 = 2376.2$$

$$r_{B.B.} = \sqrt{\frac{2376.2}{25.5}} = 9.6''$$

$l = 12' = 300''$

$l \div r_{A.A.} = 300 \div 5.9 = 50.8$

$P_L = 10000 \div 45 \times 50.8 = 7714^{\#}$

$P_D = 20000 - 90 \times 50.8 = 15428^{\#}$

$A_L = 72900 \div 7714 = 9.45\,\square''$

$A_D = 25200 \div 15428 = \underline{1.63}\,\square''$

$11.08\,\square''$

Average allowable unit stress for live and dead loads = 98100 ÷ 11.08 = 8853#

Efficiency for live and dead loads = $\frac{25.5}{11.08}$ = 230%.

The direct wind stress is more than 30% of the live and dead load stress, so must be considered.

Stress due to weight.

$4 - 4'' \times 4'' \times \frac{3}{8}''$ Ls @ 9.7# = 38.8# per ft.

2 web Pls $16'' \times \frac{7}{16}''$ @ 23.8# = 47.6# " "

Add 30% for details 25.9# " "

112.3# " "

The stress due to weight may be found by the formula $S = \frac{My}{I \pm \frac{Pl^2}{10E}}$ (See Johnson p.155) in which M is the max. moment due to weight = $12 \times \frac{wl^2}{8}$.

$= \frac{12 \times 112.3 \times 25^2}{8} = 105000$ in. lbs.

P = direct stress = L.L. + D.L. + W.L. = 133600#

l = length of member in inches = 300"

I = moment of inertia about axis A.A.

S = unit extreme fiber stress.

$S = \frac{105000 \times 8.25}{894.75 - \frac{133600 \times 300^2}{10 \times 28{,}000{,}000}} = 983$# This is more than 10% of the live and dead load unit stress so must be considered.

Allowable unit stress considering wind and weight = 1.40 × 8853# = 12394#

Actual unit total stress = 134583 ÷ 25.5 = 6221#

Efficiency = 12394 ÷ 6221 = 198%

U_1U_2 — L.L. = 145000#, D.L. = 48600#, W.L. = 59600#

Composition same as U_0U_1

$A_L = 145000 \div 7714 = 18.68\,\square''$

$A_D = 48600 \div 15428 = \underline{3.15}\,\square''$

$21.83\,\square''$

Allowable unit stress for live and dead loads = 193600 ÷ 21.83 = 8860#

Efficiency for live and dead loads = $\frac{25.5}{21.83}$ = 116%

The wind stress is greater than 30% of the live and dead load stress so must be considered.

Stress due to weight.

$$S = \frac{105000 \times 8.25}{894.75 - \frac{253600 \times 300^2}{10 \times 28{,}000{,}000}} = 1066\text{\#}$$

This is greater than 10% of the live and dead load stress so must be considered

Allowable unit stress considering wind and weight = 1.40 × 8860# = 12404#

Actual unit stress = 254260 ÷ 25.5 = 10974#

Efficiency considering wind and weight = 12404 ÷ 10974 = 113%

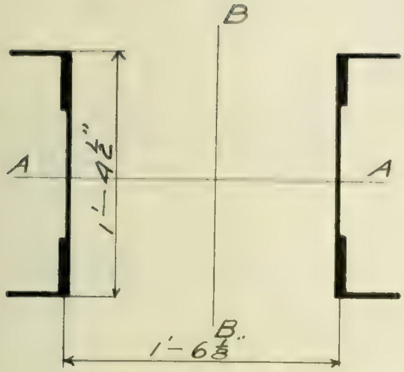
U_2U_3 — L.L. = 206,000#, D.L. = 68400#, W.L. = 59600#

Composition =

2 Web Pls. $16'' \times \frac{9}{16}''$, Area = $18\,\square''$

4 Ls $4'' \times 4'' \times \frac{1}{2}''$ " = $\underline{15}\,\square''$

$33\,\square''$



$$I_{A.A.} = 4(5.56 + 3.75 \times 7.07^2) + \frac{2 \times 9 \times 16^3}{12 \times 16}$$

$$= 772 + 384 = 1156$$

$$r_{A.A.} = \sqrt{\frac{1156}{33}} = 5.4''$$

$$l = 12' = 300''$$

$$l \div r_{A.A.} = 300 \div 5.4 = 58.8''$$

$$P_L = 10000 - 45 \times 58.8 = 7354^{\#}$$

$$P_D = 20000 - 90 \times 58.8 = 14708^{\#}$$

$$A_L = 206000 \div 7354 = 28.01^{\square''}$$

$$A_D = 68400 \div 14708 = \underline{4.64}^{\square''}$$

$$32.65^{\square''}$$

Allowable unit stress for live and dead loads = 274400 ÷ 32.65 = 8404#

Efficiency = 33 ÷ 32.65 = 101%

The wind stress is less than 10% of the live and dead load stress so need not be considered.

Stress due to weight.

2 Web Pls 16"×9/16" @ 30.6#	= 61.2#	per ft.
4 Ls 4"×4"×½" @ 12.8#	= 51.2#	" "
	112.4#	
Add 30% for details	33.7	
	146.1#	" "

Max. moment due to weight $= \frac{146 \times 25^2 \times 12}{8}$

$= 136875$ in. lbs.

$$S = \frac{136875 \times 8.25}{964 - \frac{274400 \times 300^2}{10 \times 28000000}} = 1280^{\#}$$

This is more than 10% of the live and dead load

stress so must be considered. Allowable unitstress considering weight $= 1.10 \times 8404^{\#}$

$= 9244^{\#}$

Efficiency $= \dfrac{9244}{8314 + 1280} = 96\%$

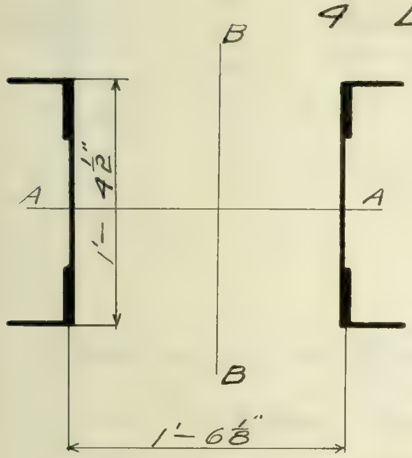
$U_3 U_4$ – L.L. $= 206{,}000^{\#}$, D.L. $= 79300^{\#}$, W.L. $= 58400^{\#}$

Composition. (Same as $U_2 U_3$

2 web Pls $16'' \times \frac{9}{16}''$ Area $= 18 \square''$

4 Ls $4'' \times 4'' \times \frac{1}{2}''$ .. $= 15 \square''$

$33 \square''$



$I_{A.A} = 1156$, $r_{A.A} = 5.1$, $l = 300''$

$l \div r = 300 \div 5.1 = 58.8$

$P_L = 10000 - 45 \times 58.8 = 7354^{\#}$

$P_D = 20000 - 90 \times 58.8 = 14708^{\#}$

$A_L = 206000 \div 7354 = 28.01$

$A_D = 79300 \div 14708 = 5.39$

33.40

Allowable unitstress for live and dead loads $= 285300 \div 33.4 = 8541^{\#}$

Efficiency for live and dead loads $= 33 \div 33.4$

$= 98.8\%$

The wind stress is less than 30% of the live and dead load stress so need not be considered.

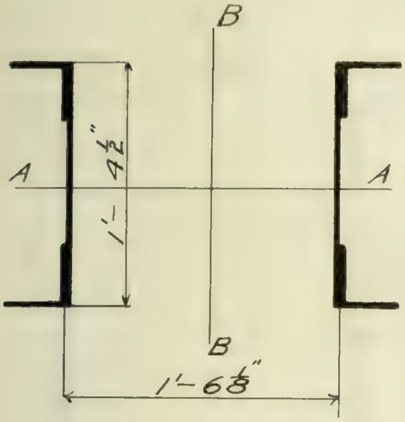
Stress due to weight $= 1280^{\#}$ (Same as $U_2 U_3$).

Allowable unitstress considering weight $= 1.10 \times 8541 = 9395^{\#}$

Efficiency $= \frac{9395}{8645+1280} = 94.6\%$

$U_1 U_{1\frac{1}{2}}$ — L.L. = +221,470#, D.L = +86700#, W.L. = +76400#

Composition of Member. (Same as $U_2 U_3$).



Area = 33 □"

$I_{A.A.} = 1156$, $r_{A.A.} = 5.1''$

$l = 12.74' = 152.8''$

$l \div r = 152.8 \div 5.1 = 30$

$P_L = 10000 - 45 \times 30 = 8650$#

$P_D = 20000 \div 90 \times 30 = 17300$#

$A_L = 221470 \div 8650 = 25.6$ □"

$A_D = 86700 \div 17300 = \underline{5.01}$ □"

30.61 □"

Average allowable unit stress for live and dead loads = 308170 ÷ 30.61 = 10060#

Efficiency for live and dead loads = $\frac{10060}{30.61}$ = 106%

The wind stress may be neglected since it is less than 30% of the live and dead load stress.

Stress due to weight.

$P = L.L. + D.L. = 308,170$# cos. θ = .93

$$M = 12 \times \tfrac{1}{8} w l^2 = \frac{12 \times 112 \times 12.74^2}{8} = 27267.6$$

$$S = \frac{27267.6 \times 8.25 \times .93}{894.75 - \frac{308170 \times 152.9^2}{10 \times 28000,000}} = 285\#$$

This stress may be neglected since it is less than 10% of the live and dead load unit stress.

Lower Chord.

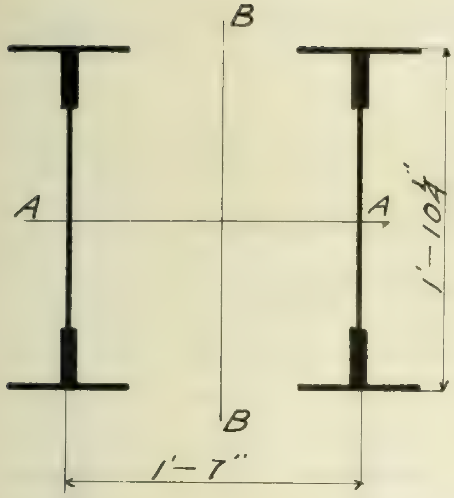
L_0L_1 – L.L. = +451800#, D.L. = +178500#, W.L. = ±

Composition of member.

2 Webs $22'' \times \frac{3}{4}''$ Area = $33^{\square''}$

8 Ls $4'' \times 4'' \times \frac{9}{16}''$ .. = $\underline{33.44}^{\square''}$

Total .. = $66.44^{\square''}$



$$I_{A.A.} = 8(6.12 + 4.18 \times 9.91^2) + \frac{2 \times 3 \times 22^3}{12 \times 4}$$

$$= 3333 + 1331 = 4664$$

$$r_{A.A} = \sqrt{\frac{4664}{66.44}} = 8.3''$$

$$l = 26.09' = 313.''$$

$$l \div r = 313 \div 8.3 = 37.7$$

$$P_L = 10000^{\#} - 45 \times 37.7 = 8303^{\#}$$

$$P_D = 20000^{\#} - 90 \times 37.7 = 16605^{\#}$$

$$A_L = 451800 \div 8303 = 54.41^{\square''}$$

$$A_D = 178500 \div 16605 = \underline{10.74}$$

$$64.15$$

Allowable unit stress for live and dead loads = 630300 ÷ 65.15 = 9674#

Efficiency for live and dead loads = $\frac{9674}{9486}$ = 101%.

The wind load is less than 30% of the live and dead load, so need not be considered. (Cooper Par.)

Stress due to weight.

2 web Pls $22'' \times \frac{3}{4}''$ @ 56.1# = 112.2#

8 Ls $4'' \times 4'' \times \frac{9}{16}''$ 14.2# = $\underline{113.6}$#

225.8#

Add 30% for details = $\underline{67.7}$#

Total wt. per ft. = 293.5#

$M = 12 \times \frac{1}{8} wl^2 = \frac{12 \times 293.5 \times 26.09^2}{8} = 299673$ in lbs.

$P = 630300^{\#}$, $\quad \cos\theta = .883$

$$S = \frac{299673 \times 11 \times .882}{4664 - \frac{630300 \times (37.7 \times 12)^2}{10 \times 28{,}000{,}000}} = 692^{\#}$$ This is less than 10% of the live and dead load unit stress so need not be considered.

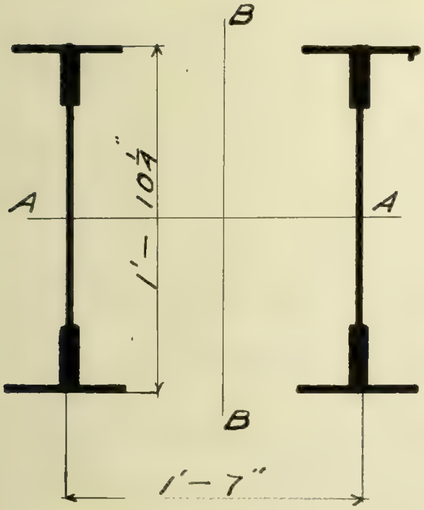
L_1L_2 — L.L. $= +393{,}250^{\#}$, D.L. $= +148{,}200^{\#}$ W.L. $= \pm$

Composition of member.

2 Web Pls $22'' \times \frac{9}{16}''$, Area $= 24.75^{\square''}$

8 $\angle$s $4'' \times 4'' \times \frac{9}{16}''$ $\quad$ .. $= \underline{33.44^{\square''}}$

Total .. $= 58.19^{\square''}$



$I_{A.A.} = 3333 + \frac{8 \times 9 \times 22^3}{12 \times 16} = 4331$

$r_{A.A.} = \sqrt{\frac{4331}{58.2}} = 8.62''$

$l = 25.79' = 309.48''$

$l \div r = 309.48 \div 8.62 = 35.8''$

$P_L = 10000 - 45 \times 35.8 = 8389^{\#}$

$P_D = 20000 - 90 \times 35.8 = 16778^{\#}$

$A_L = 393250 \div 8389 = 46.87^{\square''}$

$A_D = 148200 \div 16778 = \underline{8.83^{\square''}}$

$55.70^{\square''}$

Allowable unit stress for live and dead loads $= 541450 \div 55.7 = 9720^{\#}$

Efficiency for live and dead loads $= \frac{58.19}{55.7} = 104\%$

The stress due to wind is less than 30% and that due to weight less than 10% of the live and dead load stress, hence may be neglected.

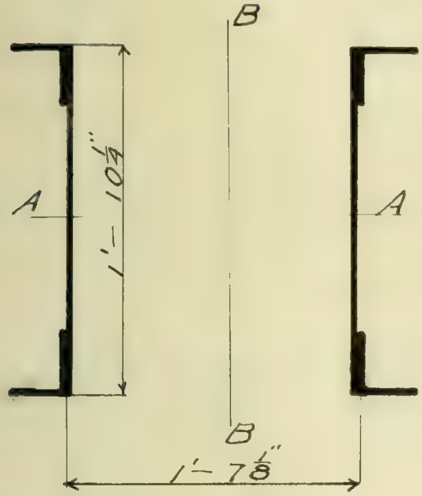
L_2L_3 — L.L. = + 350,220#, D.L. = +119,300#, W.L. = ± 97,210#

Composition of member.

2 Web Pls $22'' \times \frac{3}{4}''$ Area = 33 □"

4 ∠s $4'' \times 4'' \times \frac{3}{4}''$ .. = 21.76 □"

Total .. 54.76 □"



$$I_{A.A.} = 4(7.66 + 4.18 \times 9.86^2) + \frac{2 \times 3 \times 22^3}{12 \times 4}$$

$$= 3259$$

$$r_{A.A.} = \sqrt{\frac{3259}{54.76}} = 7.7$$

$$l = 25.18' = 302.16''$$

$$l \div r = 302.16 \div 7.7 = 39.2$$

$$P_L = 10000 - 45 \times 39.2 = 8256\#$$

$$P_D = 20000 - 90 \times 39.2 = 16512\#$$

$$A_L = 350220 \div 8256 = 42.42 □''$$

$$A_D = 119300 \div 16512 = 7.22 □''$$

49.64 □"

Average allowable unit stress for live and dead loads = 469520 ÷ 49.64 = 9257#

Efficiency for live and dead loads = $\frac{54.76}{49.64}$ = 108%

The stress due to wind is less than 30% and that due to weight is less than 10% of the live and dead load stress hence may be neglected. (Cooper Par. 37.)

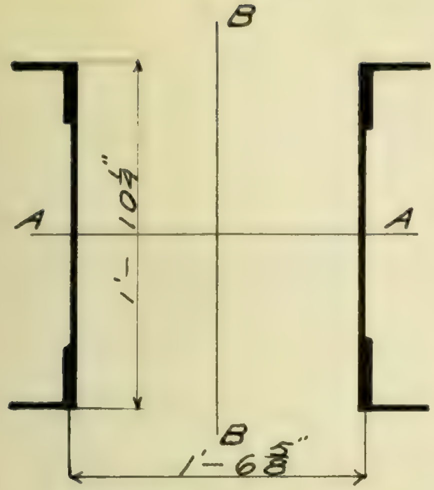
L_3L_4 — L.L. = + 307480#, D.L. = + 93200#, W.L. = 119,960#

Composition of member.

2 Web Pls $22'' \times \frac{9}{16}''$, Area = 24.75 □"

4 ∠s $4'' \times 4'' \times \frac{9}{16}''$ .. = 16.72 □"

Total .. = 41.47 □"



$I_{A.A.} = 4(6.12 + 4.18 \times 9.91^2) + \frac{2 \times 9 \times 22^3}{12 \times 16}$

$= 1666.5 + 998 = 2665$

$r_{A.A} = \sqrt{\frac{2665}{41.47}} = 8.01$

$l = 23.97' = 287.64''$

$l \div r = 287.64 \div 8.01 = 35.9'$

$P_L = 10000 - 45 \times 35.9 = 8384^{\#}$

$P_D = 20000 - 90 \times 35.9 = 16768^{\#}$

$A_L = 307480 \div 8384 = 36.67^{\square''}$

$A_D = 93200 \div 16768 = \underline{5.55}^{\square''}$

Total $= 42.22^{\square''}$

Average allowable unit stress for live and dead loads $= 400680 \div 42.22 = 9490^{\#}$

Efficiency for live and dead loads $= \frac{41.47}{42.22} = 98\%$

Stress due to wind and weight of member are too small to be considered. (See Cooper Par.)

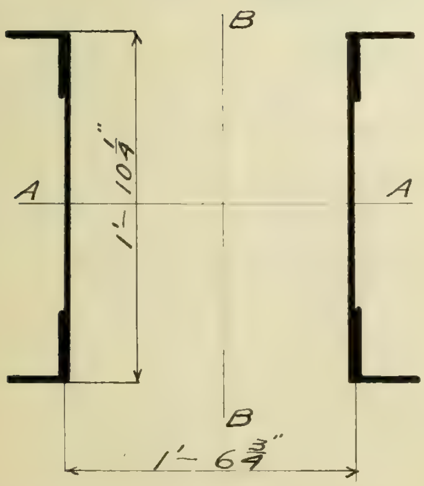
$L_4 L_{4\frac{1}{2}}$ — L.L. $= +221470^{\#}$, D.L. $= +86700^{\#}$, W.L. $= \pm 121960^{\#}$

Composition of member.

2 Web Pls $22'' \times \frac{9}{16}''$ Area $= 24.75^{\square''}$

4 Ls $4'' \times 4'' \times \frac{3}{8}''$ " $= \underline{11.49}^{\square''}$

Total " $= 36.2^{\square''}$



$I_{A.A.} = 4(4.36 + 2.86 \times 10^2) + \frac{2 \times 9 \times 22^3}{12 \times 16}$

$= 1161.4 + 998 = 2159$

$r = \sqrt{\frac{2159}{36.2}} = 7.8''$

$l = 12.74 = 152.88$

$l \div r = 152.88 \div 7.8 = 19.6$

$P_L = 10000 - 46 \times 19.6 = 9118^{\#}$

$P_o = 20000^{\#} - 90 \times 19.6 = 18236^{\#}$

$A_L = 221470^{\#} \div 9118 = 24.28^{\square''}$

$A_o = 86700^{\#} \div 18236 = 4.75^{\square''}$

Total $= 29.03^{\square''}$

Average allowable unit stress for live and dead loads $= 308170 \div 29.03 = 10615^{\#}$

Actual unit stress for live and dead loads $= \dfrac{221470 + 86400}{36.2} = 8504^{\#}$

Efficiency for live and dead loads $= \dfrac{36.2}{29.03} = 124\%$

Stress due to weight.

2 Web Pls $22 \times \frac{9}{16}''$ @ $42.04^{\#} = 84.08^{\#}$

4 Ls $4'' \times 4'' \times \frac{3}{8}''$ @ $9.7^{\#} = 38.8^{\#}$

Add 30% for details $= \underline{36.86^{\#}}$

Total weight per ft $= 159.74^{\#}$

$P = 430130^{\#}$ $\quad \cos\theta = .92$

$$M = \frac{159.74 \times 12.74^2 \times 12 \times .92}{8} = 35778$$

$$S = \frac{35778 \times 11}{2159 - \dfrac{430130 \times 153^2}{10 \times 28000000}} = 185^{\#}$$

This stress is too small to consider.

Allowable unit stress considering wind $= 1.30 \times 10615 = 13800^{\#}$

Actual unit stress considering wind $= 8504^{\#} + \dfrac{121960}{36.2} = 8504^{\#} + 3370^{\#} = 11874^{\#}$

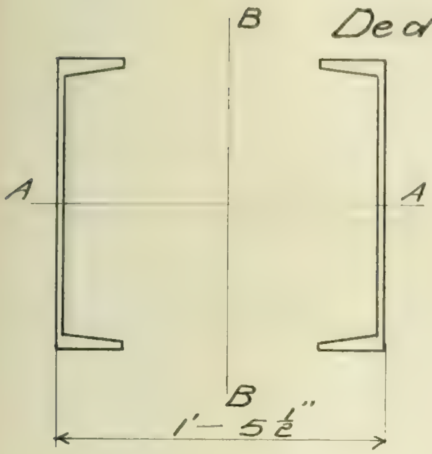
Efficiency $= 13800 \div 11874 = 116\%$

Art 5. Tension Members.

U_0L_1 — L.L. = −145,350#, D.L. = −50,400#, W.L. = −74,200#

Composition of member.

2−15″−35# [s. Area = 20.58 □″



Deduct for 8 rivets 3.44 □″

Net area = 17.14 □″

$P_L = 10000$#

$P_D = 20000$#

$A_L = 145,350\# \div 10,000 = 14.54$ □″

$A_D = 50,400\# \div 20,000 = 2.52$ □″

17.06 □″

Average allowable unit stress for live and dead loads = 195750 ÷ 17.06 = 11470#

Actual unit stress = 195750 ÷ 17.14 = 11420

Efficiency = 11470 ÷ 11420 = 100.4 %

The direct wind stress must be considered since it is more than 30 % of the live and dead load stress

Stress due to weight.

$$S = \frac{My\cos\theta}{I + \frac{Pl^2}{10E}} = \frac{\frac{1}{8} \times 70 \times 32^2 \times 7.5 \times \frac{23}{45.8} \times 12}{639.8 + \frac{270150\,(12 \times 32)^2}{10 \times 28,000,000}}$$

$$= \frac{202500}{639.8 + 144.6} = 51.6\#$$

This stress is too small to consider. (Cooper Par. 40)

Allowable unit stress considering wind = 1.3 × 11470 = 14911#

Actual unit stress = $11420 + \frac{74200}{17.14} = 15749$#

Efficiency = 14911 ÷ 15749 = 94 %

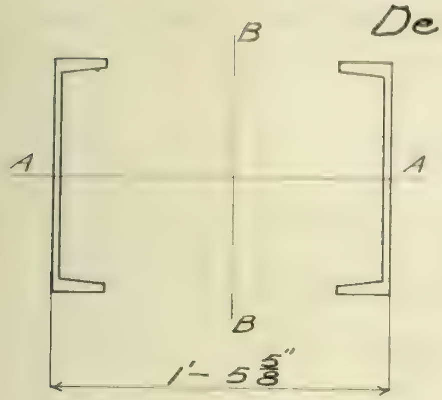
U_1L_2 — L.L. = −115650# D.L. = −37300# W.L. =

Composition of member.

2 − 12" − 25# [s   Area = 14.7□"

Deduct for 6 rivets 2.3□"

Net area = 12.4□"



$I_{A.A.} = 2 \times 144 = 288$

$P_L = 10000\#$

$P_D = 20000\#$

$A_L = 115650 \div 10000 = 11.565□"$

$A_D = 37300 \div 20000 = \underline{1.865}□"$

13.43□"

Average allowable unit stress for live and dead load = 152950 ÷ 13.43 = 11387#

Actual unit stress = 152950 ÷ 12.4 = 12334#

Efficiency = 11387 ÷ 12334 = 92%

The stress due to wind and that due to weight are too small to consider.

U_2L_3 — L.L. = −91500# D.L. = −24900# W.L. = 17180#

Composition of member.

2 − 12" − 25# [s Net area = 12.4□"

$P_L = 10000\#$, $P_D = 20000\#$

$A_L = 91500 \div 10000 = 9.15□"$

$A_D = 24900 \div 20000 = \underline{1.24}□"$

10.39□"

Average allowable unit stress for live and dead load = 116400 ÷ 10.39 = 11200#

Actual unit stress = 116400 ÷ 12.4 = 9389#

Efficiency = 11200 ÷ 9389 = 119%

The stress due to wind, and that due to weight of member are too small to consider.

U_3L_4 — L.L. = −108900,# D.L. = −12400, W.L. = 22500#

Composition of member.

2 Eye bars $5'' \times 1\frac{3}{16}''$ Area = 11.87 □"

A_L = 108900 ÷ 10000 = 10.89 □"

A_D = 12400 ÷ 20000 = .62 □"

11.51 □"

Average allowable unit stress for live and dead loads = 121300 ÷ 11.51 = 10538#

Actual unit stress = 121300 ÷ 11.87 = 10218#

Efficiency = 10538 ÷ 10218 = 102%.

The stress due to wind, and that due to weight of member are too small to consider. (See Cooper Par. 37)

L_3U_4 — L.L. = −90400,# D.L. = +14500,# W.L. = ±29200

Composition of member.

2-Eye bars $4'' \times 1\frac{1}{16}''$. Area = 8.5 □"

A_L = 75900 ÷ 10000 = 7.59 □"

Allowable unit stress = 10000#

Efficiency = $10000 \div \frac{75900}{8.5}$ = 111%.

The direct wind stress must be considered since it is greater than 30% of the live and

dead load stress.

The stress due to weight is less than 10% of the live and dead load stress so may be neglected. (Cooper Par. 10).

Allowable unit stress considering wind = 1.30 × 10000 = 13000#

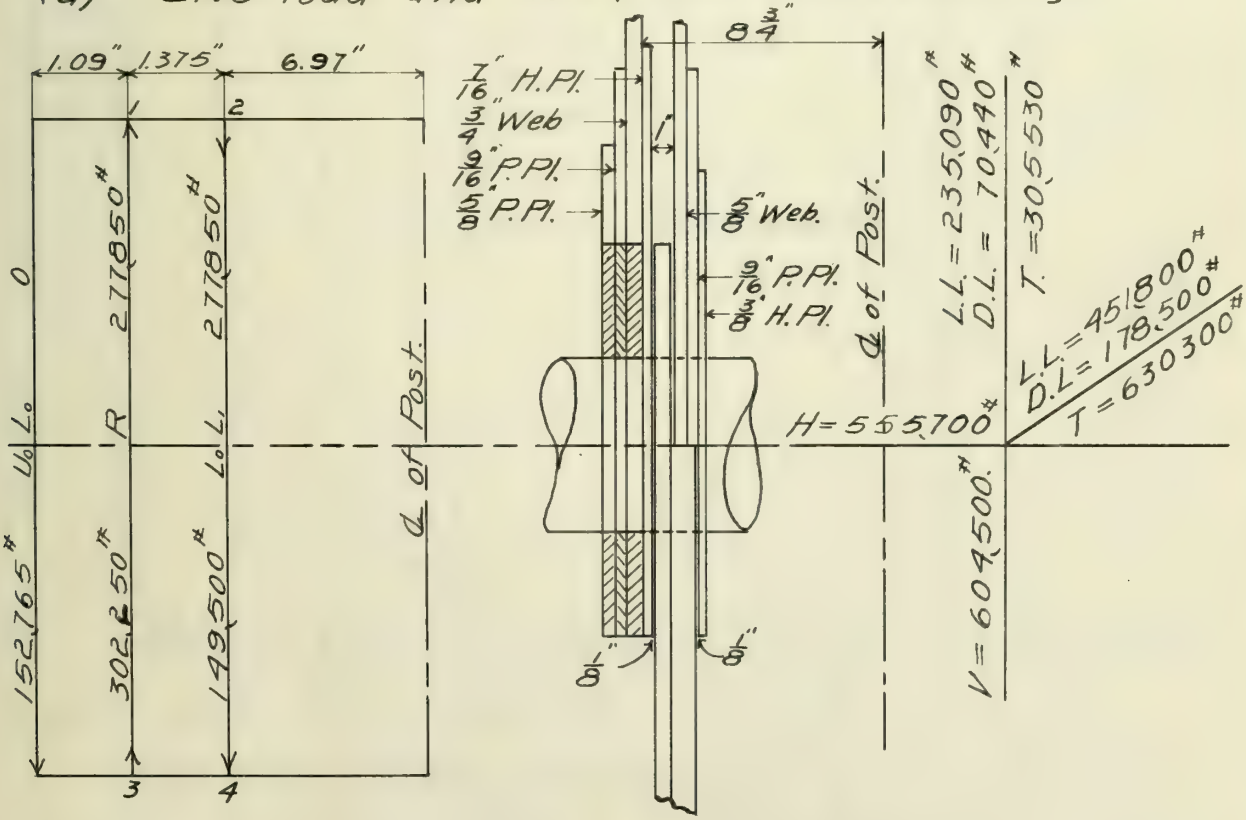
Actual unit stress = 8930# + 3482 = 12412#

Efficiency = 13000 ÷ 12412 = 104%

Art. 6. Moment on Pins.

Pin L_0 — $8\frac{7}{8}$" × 2'–$2\frac{1}{8}$" Grip.

(a) Live load and dead load stress acting.



Horizontal component of stress at 1 = 0

" 2 = 1.375 × 277850 = 382,044

Vertical component of moment

at 3 = 1.09 × 152760 = 166,508

" 4 = 1.375 × 302250 = 2.465 × 152760

= 415594 − 373498 = 42096.

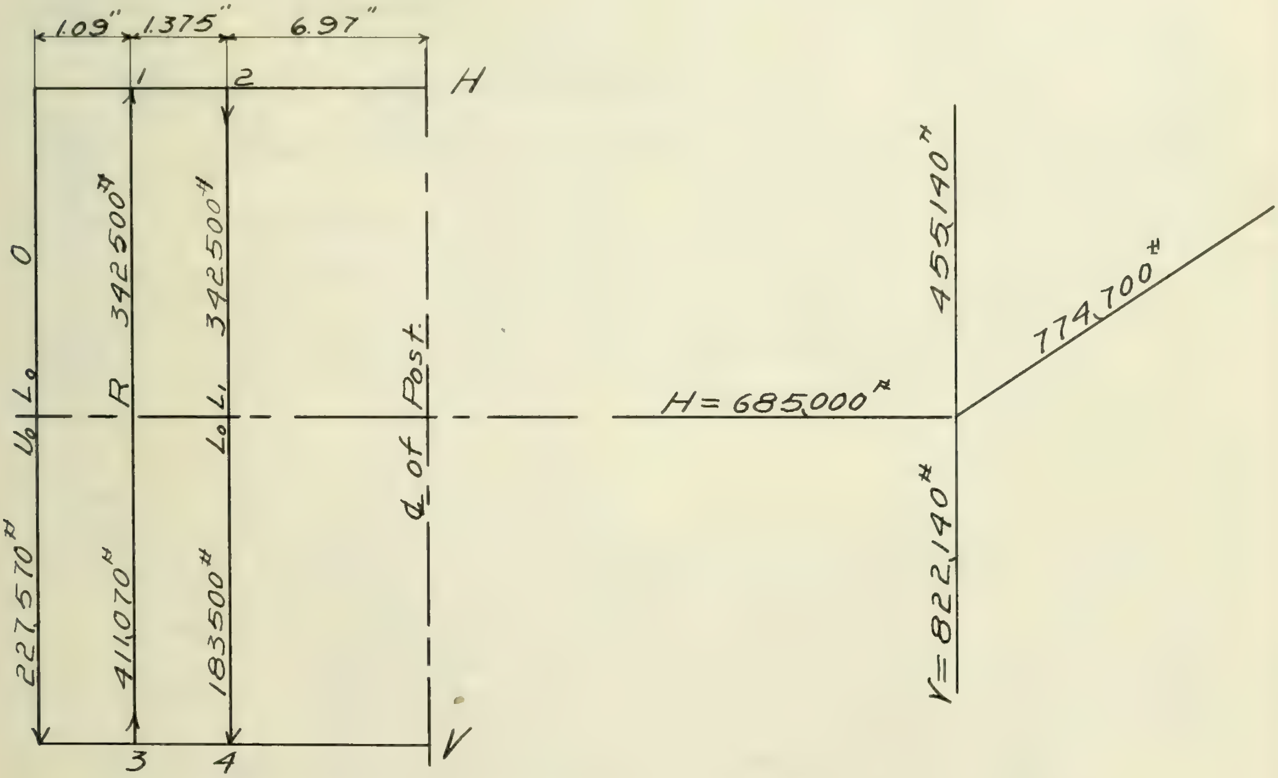
Max. moment at 2 and 4 = $\sqrt{382044^2 + 42096^2}$

= 384300

Allowable moment = 1235310

Efficiency = 1235310 ÷ 384300 = 322%

(b) Wind acting.



Horizontal component of moment

at 2 = 1.375 × 342500 = 470938

Vertical component of moment

at 4 = 1.375 × 411070 − 2.465 × 227570

= 565221 − 560960 = 4261

Max moment at 2 and 4 = $\sqrt{470938^2 + 4261^2}$ = 471000

The wind stress does not increase the moment 30% therefore need not be considered.

Pin $U_{4\frac{1}{2}}$. — $4\frac{5}{16}'' \times 20\frac{3}{8}''$ Grip.

This is a riveted connection, hence the moment on the pin, if there is any, is probably too small to consider.

Pin U_3 — $4\frac{5}{16}'' \times 18\frac{3}{8}''$ Grip.

Eccentricity of stress = 1.22"

Max. stress in member = 121300# ÷ 2 = 60650.0#

Max. moment in pin = $\frac{1.22 \times 121300}{2}$ = 74000 in.lbs.

Allowable moment = 141000 in. lbs.

Efficiency = 141000 ÷ 74000 = 190%.

Pin U_4 — $4\frac{5}{16}'' \times 20''$ Grip.

Max. stress = 75900.0# ÷ 2 = 37950.0#

Eccentricity of stress = 2.04"

Max. moment = 2.04 × 37950 = 77418 in. lbs.

Efficiency = 141000 ÷ 77418 = 182%

Pin L_3 — $4\frac{5}{16}'' \times 20\frac{1}{4}''$ Grip.

Eccentricity of stress = 1.53"

Max. moment = 1.53 × 37950 = 58000 in. lbs.

Efficiency = 141000 ÷ 58000 = 300%

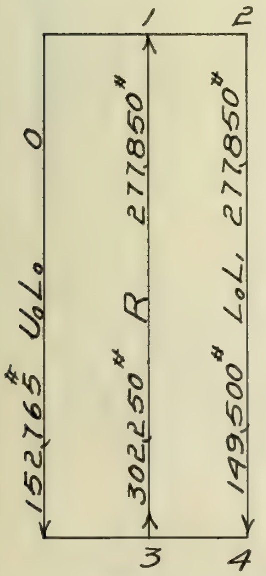
Pin. L_4. Efficiency same as U_3 = 190%

Art. 7. Bearing on Pins.

Pin.	Member.	Stress.	Section.	Bearing Area Sq. ins	Unit Comp. on Pin.	Efficiency per cent.
L_0	Reaction	408000#	$3\frac{5}{16}'' \times 8\frac{7}{8}''$	29.4	13850#	108%
	U_0L_0	227570#	$1\frac{9}{16}'' \times 8\frac{7}{8}''$	13.9	1632#	120%
	L_0L_1	315150#	$2\frac{3}{8}'' \times 8\frac{7}{8}''$	21.08	10206#	147%
U_3	U_3U_4	60650#	$1\frac{3}{8}'' \times 4\frac{5}{16}''$	6.03	10100#	140%
	U_3L_4	60650#	$4\frac{5}{16}'' \times 1\frac{3}{16}''$	5.1	11920#	126%
L_3	L_3L_4	37950#	$2'' \times 4\frac{5}{16}''$	8.62	4400#	340%
	L_3U_4	37950#	$1\frac{1}{16}'' \times 4\frac{5}{16}''$	4.57	8300#	180%
U_4	L_3U_4	37950#	$1\frac{1}{16}'' \times 4\frac{5}{16}''$	4.57	8300#	180%
	U_3U_4	37950#	$2\frac{3}{8}'' \times 4\frac{5}{16}''$	10.35	2800#	535%
L_4	L_3L_4	60650#	$1\frac{1}{4}'' \times 4\frac{5}{16}''$	5.4	1100#	136%
	U_3L_4	60650#	$1\frac{3}{16}'' \times 4\frac{5}{16}''$	5.1	11920#	126%
$U_{4\frac{1}{2}}$	$U_4U_{4\frac{1}{2}}$	278000#	$3\frac{7}{16}'' \times 8\frac{7}{8}''$	30.5	9150#	164%
	$L_4L_{4\frac{1}{2}}$	"	" "	"	"	"

Art. 8 Shear in Pins.

Pin L_0



Horizontal component of shear between 1 and 2 = 277850#

Vertical component of shear between 0 and 3 = 152765#

3 " 4 = 149500#

Max shear $= \sqrt{27785^2 + 149500^2} = 315000$#

Unit max. shear = 315000 ÷ 61.86

= 5090#

Efficiency = 9000 ÷ 5090 = 176%

Pin $U_{4\frac{1}{2}}$. There is a riveted connection here, hence there can be no shear in the pin.

Pin U_3 Max shear equals the stress in U_3L_4 $= 121300^{\#}$

Unit shear $= 121300^{\#} \div (2 \times 13.77) = 4400^{\#}$

Efficiency $= 9000 \div 4400^{\#} = 202\%$

Pin U_4. Max. shear equals stress in L_3U_4 $= 37950^{\#}$

Unit shear $= 37950 \div 13.77 = 2750^{\#}$

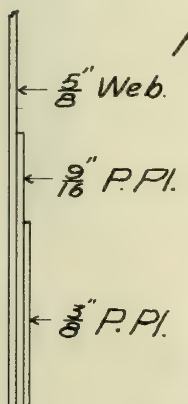
Efficiency $= 9000 \div 2750 = 327\%$.

Pin L_3. Max shear equals that in U_4

Efficiency $= 327\%$.

Pin L_4. Efficiency same as in $U_3 = 202\%$

Art 9. Shear of rivets in pin plates.



Post U_0L_0 at L_0

$L.L. + D.L. = 305530^{\#}$

Stress in one side $= 152765^{\#}$

Part of stress taken by $\frac{3}{8}''$ pin plate $= \frac{3}{8} \times \frac{16}{25} \times 152765 = 36663^{\#}$

Area of $24 - \frac{7}{8}''$ rivets $= 24 \times .6013^{\square''}$ $= 14.43^{\square''}$

Unit shear $= 36663 \div 14.43 = 2540^{\#}$

Efficiency $= 9000 \div 2540 = 355\%$

Unit shear when wind acts $= \frac{.24 \times 455140}{14.43 \times 2}$ $= 3775^{\#}$

Efficiency $= \frac{1.3 \times 9000}{3775} = 310\%$

Proportion of shear causing stress in rivets in $\frac{5}{8}''$ plate $= \frac{15}{16} \times \frac{16}{25} \times 152765^{\#} = 91659^{\#}$

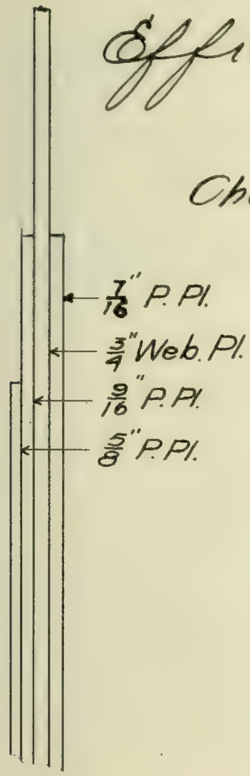
Area of 42 rivets in shear $= 42 \times .6013 = 25.25^{\square''}$

Unit shear $= 91659 \div 25.25 = 3600 = 250\%$

Efficiency $= 9000 \div 3600 = 250\%$

Unit shearing stress when wind acts

$= \frac{15}{16} \times \frac{16}{25} \times \frac{455140^{\#}}{25.25 \times 2} = 5400^{\#}$



Efficiency $= 9000 \div 5400 = 116\%$

Chord L_0L_1

Max. live and dead load stress

$= 630,300^{\#}$

Stress in one side $= 315,150^{\#}$

Proportion of stress taken by $\frac{5}{8}''$ plate $= \frac{5}{8} \times \frac{8}{19} \times 315150^{\#} = 82,900^{\#}$

Area of 36 rivets $= 36 \times .6013 = 21.64^{\square''}$

Unit shearing stress $= 82900 \div 21.64$

$= 3825^{\#}$

Efficiency $= 9000 \div 3825 = 235\%$

Proportion of stress taken by rivets in $\frac{9}{16}''$ plate $= \frac{9}{16} \times \frac{8}{19} \times 315,150^{\#} = 157,575^{\#}$

Area of 44 rivets $= 44 \times .6013 = 26.45^{\square''}$

Unit shearing stress $= 157575 \div 26.45 = 5940^{\#}$

Efficiency $= 9000 \div 5940 = 150\%$

Proportion of stress taken by rivets in $\frac{7}{16}''$ plate $= \frac{7}{16} \times \frac{8}{19} \times 315150 = 58100^{\#}$

Unit shear = 58100 ÷ 26.45 = 2210#
Efficiency = 9000 ÷ 2210 = 407 %

Art. 10. Bearing on rivets.

Post U_0L_0 at L_0

Stress in one side of post = 152765.#
Bearing stress transferred by rivets to web plate = $\frac{15}{16} \times \frac{16}{25} \times 152765 = 91659$#
Bearing area in web = .42 × .4 × $\frac{7}{8}$ = 14.7 □"
Unit bearing stress = 91659 ÷ 14.7 = 6220#
Efficiency in bearing = 15000 ÷ 6220 = 245 %

Diagonal U_0L_1

Stress in one side = 195750# ÷ 2 = 97875#
Number of rivets in web, 32
Thickness of web = .43"
Bearing area of rivets = $\frac{7}{8}$ × .43 × 32 = 12.2 □"
Unit bearing stress 97875 ÷ 12.2 = 8000#
Efficiency in bearing = 9000 ÷ 8000 ÷ 112 %

Art. 11 Rivet Spacing.

The rivet spacing apparently agrees with Coopers specifications. (See Cooper Par. 51)

Art. 12. Girders.

Composition of Girders.

	Area.	Weight.
Web Pl. $40'' \times \frac{3}{8}'' \times 23'-0''$	$15^{\square''}$	$1173^{\#}$
2 Upper flange ∠s, $6'' \times 6'' \times \frac{3}{4}''$,	$16.88^{\square''}$	$1320^{\#}$
2 Lower " " " " "	16.88	$1320^{\#}$
Add 20% of weight for details		$763^{\#}$
Total =		$4576^{\#}$

Wt. per ft = $4576 \div 23 =$ say $200^{\#}$

Dead Load per Stringer per lineal ft.

Track $200^{\#}$

Stringer $\underline{200}^{\#}$

Total $400^{\#}$

Total wt. per Stringer $= 23 \times 400^{\#} = 9200^{\#}$

Dead Load Max. Mom. $= \dfrac{9200 \times 23 \times 12}{8} = 317{,}400$ in.lbs.

Live Load Max Mom. $= \dfrac{5}{4} \times \dfrac{530800 \times 12}{2 \times 4} = \underline{3981\,000}$

Total Mom. $= 4{,}298{,}400$

Flange Area (one side) $= 16.88^{\square''}$

Deduct for 2 – 1" rivet holes $\underline{1.5}^{\square''}$

Net Area $= 15.38^{\square''}$

Max. Flange stress $= 4{,}298{,}400 \div 34.98 = 123{,}000^{\#}$

Unit " " $= 123000 \div 15.38 = 8000^{\#}$

Allowable unit stress $= 9000^{\#}$

Efficiency $= 9000 \div 8000 = 112$ %.

Max. end shear $= \frac{107900 \times 5}{2 \times 4} = 67438$ (See Cooper P. 30)

Area of web $= 15^{\square''}$

Deduct for 10 – 1" rivet holes $3.75^{\square''}$

Net area $= 15 - 3.75 = 11.25^{\square''}$

Max. unit shear $= 67438 \div 11.25 = 6000^{\#}$

Allowable unit shear $= 6000^{\#}$ (Lewis Specifications.)

Efficiency = 100 %

Stiffeners.

The distance between stiffeners need not be less than the effective depth of the girder and must not be greater than 5', and must be used within these limits whenever the unit shearing stress exceeds that given by the formula $P = 10000 - 75H$ where H is the ratio of the depth to the web thickness. In this case $H = \frac{34.94}{3/8} = 93.17$

$$P = 10000 - 75 \times 93.17 = 3012^{\#}$$

Max. shear at 6 ft. point $= \frac{5}{4}\left[\frac{(830 + 2\frac{1}{2} \times 90)}{23} - 10\right] = 44837$

Unit " " " " " $= 44837 = 11.25 = 2900^{\#}$

This is less than the allowable unit shear therefore a longer spacing may be used beyond this point.

End Stiffeners.

Use two $5" \times 4" \times \frac{7}{16}"$ Ls. Area $= 7.5^{\square''}$

Length of stiffeners = 38". $r = 2.3"$

Allowable unit stress $= 10000 - 45 \times \frac{38}{2.3} = 9257^{\#}$

Required area of stiffener = $67438 \div 9257 = 7.2^{\square''}$

Efficiency = $7.5 \div 7.2 = 104\%$.

Max. shear at 2'–8" point = $\frac{5}{4}\left[\frac{600 + 5\frac{1}{3} \times 80}{23}\right] = 55800^{\#}$

No. rivets required = $55800 \div 3938 = 14$.

Area of web = $15^{\square''}$ Area of 14–1" Holes = $14 \times \frac{3}{8} = 5.25^{\square''}$

Net area of web = $15 - 5.25 = 9.75^{\square''}$

Use 2 Ls $4'' \times 4'' \times \frac{7}{16}''$, Area = $6.62^{\square''}$ $r = 1.82''$

Allowable unit stress = $10000 - 45 \times \frac{38}{1.82} = 9056^{\#}$

Required area = $55800 \div 9056 = 6.1^{\square''}$

Efficiency = $6.62 \div 6.1 = 108\%$

Rivet Spacing– Lower Flange.

The pitch of rivets may be obtained by the formula $p = \frac{rh}{S}$ in which p is the pitch, h is the effective depth of the girder, and r is the shearing or bearing value of the rivet. The bearing value of a $\frac{7}{8}''$ rivet in a $\frac{3}{8}''$ plate is $\frac{3}{8}'' \times \frac{7}{8}'' \times .8 \times 15000^{\#} = 3938^{\#}$

$$p = \frac{3938 \times 34.94}{67438} = 2.04$$

The rivets must be placed in two rows.

Let d = distance in feet from the end of stringer at which pitch changes any specified amount.

Max. panel load = $200000^{\#}$

Average load per ft. per stringer = $\frac{200000}{2 \times 23} = 4350^{\#}$

$$p = \frac{rh}{S - 4350d} \quad \therefore d = \frac{S}{4350} - \frac{rh}{4350p}.$$

Substitute values of r, h, and S, we have

$$d = \frac{67438}{4350} - \frac{3938 \times 34.94}{4350p} = 15.5 - \frac{31.66}{p}.$$

When $p = 2.5''$

$$d = 15.5 - \frac{31.66}{2.5} = 2.9' = 2'-10''$$

When $p = 3''$

$$d = 15.5 - \frac{31.66}{3} = 4.95' = 4'-11''$$

When $p = 3\tfrac{1}{2}''$

$$d = 15.5 - \frac{31.66}{3.5} = 6.5' = 6'-6''$$

When $p = 4''$

$$d = 15.5 - \frac{31.66}{4} = 7.59' = 7'-7''$$

Rivet spacing – Upper Flange.

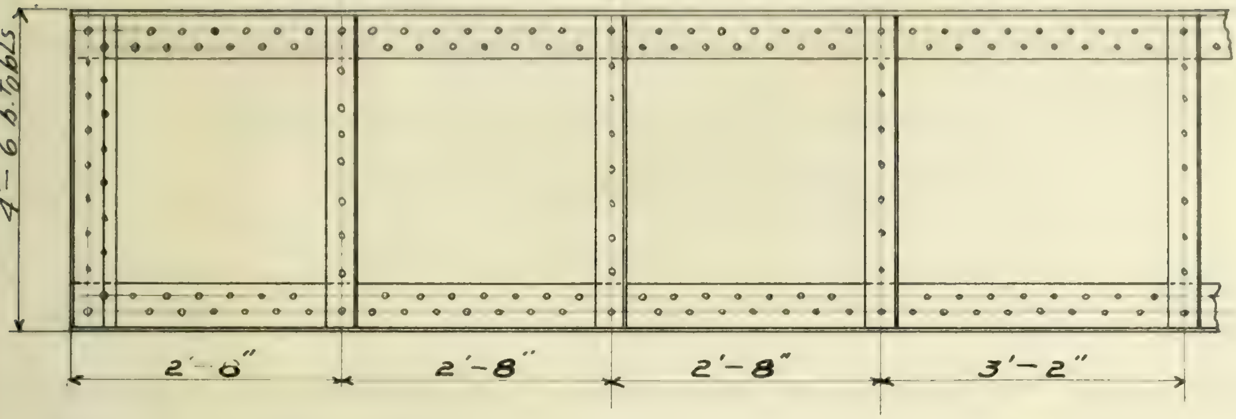
The weight on one engine wheel is 25000.# Consider this load distributed over 3 ties spaced 14" c. to c. which is equivalent to a uniform load of $\frac{25000^{\#}}{42}$ say 600# per lineal inch. In terms of p, the load in distance is 600 p,# which is the vertical bearing stress on each rivet. The horizontal stress due to moment is $r = \frac{ps}{h} = \frac{67438\,p}{35} = 1926\,p$

Resultant stress $= \sqrt{1926^2 + 600^2})p = 2017\,p.$

The rivets are in double shear, hence bearing will govern. The bearing value of $\frac{7}{8}$ rivets in $\frac{3}{8}''$ plate $= \frac{3}{8} \times \frac{7}{8} \times .8 \times 15000^{\#} = 3938^{\#} = r^{\#}$

$r = 1926p \quad \therefore p = \frac{3938}{1926} = 2.04''$. This is nearly the same as the minimum pitch found for the lower flange. A uniform pitch of 2" will be used for both lower and upper flanges.

DIAGRAM OF STRINGER.



Art. 13. Floor Beams.

Composition of Floor Beams.

Web Pl $54'' \times \frac{3}{8}''$, Area $= 20.25^{\square''}$

2 Upper Ls $6'' \times 6'' \times \frac{3}{4}''$ " $= 16.88^{\square''}$

2 Lower " " " " " $= 16.88^{\square''}$

2 Flange Pls $14'' \times \frac{7}{16}''$ " $= 12.25^{\square''}$

Area of one flange $= 16.88^{\square''} + 6.13^{\square''} = 23.01^{\square''}$

Deduct for rivet holes $\underline{2.38^{\square''}}$

Net area $= 20.63^{\square''}$

Max. floor beam reactions from live loads $= \frac{5}{4}(144300)$ $= 180375^{\#}$ (See Cooper Par 30).

Stringer end reaction $= 90187^{\#}$

Max. Bending Mom. at attachment of stringer, due to live loads $= 7 \times 12 \times 90187 = 7{,}575{,}648$ in. lbs.

Dead Load Moment.

The moment at the center of the floor beam due to live-load, weight of track, and weight of stringers is the same as at the stringer connection, and the maximum

moment due to weight of the floor beam occurs at its center, making the maximum moment at that point.

Wt of track = 4600# (See pp 62).

.. .. stringer = 4600# (See pp. 62)

Total = 9600#

[in. lbs.

Max. Moment of stringers & track = 7 × 12 × 9200 = 772,800

Moment due to weight of floor beam = $\frac{600 \times 22 \times 12}{8}$ = 198 000

Total Max. Moment = 8,546,488

Effective depth of floor beam = 44.8"

Flange stress = 8,546,488 ÷ 44.8 = 190,769#

Unit flange stress = 190,769 ÷ 20.63 = 9247#

Allowable unit stress = 10000# (Cooper par 31).

Efficiency = 10000 ÷ 9247 = 106%.

Max shear in web = 105387#

Area of web = 20.25□"

Deduct for 10 rivet holes 3.75□"

Net area = 20.25 − 3.75□" = 16.5□"

Unit shear = 105387 ÷ 16.5 = 6,387#

Efficiency in shear = 6000 ÷ 6387# = 94%

Art. 14. Floor Beam Connection.

Composition − 2−Ls 6" × 6" × ½" − Area = 5.75□"

Live Load end shear = 90187#

Dead .. .. .. = 15200#

Total = 105,387#

Shearing value of ⅞" rivets in single shear { Shop − 4329# ; Field − 2886#

Bearing value of $\frac{7}{8}$" rivets in $\frac{3}{8}$" plate $\left\{ \begin{array}{l} \text{Shop} - 3938^{\#} \\ \text{Field} - 2635^{\#} \end{array} \right.$

Number of rivets required at connection to floor beam $= 105387 \div 3938 = 27$

Actual numbers of rivets at connection bearing in web is 30

Efficiency $= 30 \div 27 = 111\%$.

Number of rivets required in connection to post $= 105387 \div 2886 = 37$

Actual number of rivets 34.

Efficiency $= 37 \div 34 = 92\%$

There are eight rivets in sway brace connection, which gives additional support to the beam, raising the efficiency to probably 100%.

Stiffeners.

The stiffeners are composed of angles $5" \times 3\frac{1}{2}" \times \frac{3}{8}" \times 52\frac{1}{2}"$ long. $r = 2.41"$, Area $= 6.1^{\square}"$

Allowable unit stress $= 10{,}000 - 45\frac{52.5}{2.41} = 9020^{\#}$

Maximum shear $= 105387^{\#}$ (See pp. 67)

Required area of of stiffeners $= \frac{105387}{9.020} = 11.6^{\square}"$

Four angles should be used in place of two as shown in drawing.

Four angles $5" \times 3\frac{1}{2} \times \frac{3}{8}"$ are used at stringer bearing. Area $= 12.18^{\square}"$

Efficiency $= 12.18 \div 11.6 = 105\%$

Number of rivets required in stiffeners $= 105387 \div 3938 = 27$ The rivets must be placed in two rows.

Flange Rivet Spacing.

Pitch of rivets $= p = \frac{rh}{S} = \frac{3938 \times 44.8}{105387} = 1.6''$

Set rivet spacing be $1\frac{5}{8}$ between post connection and stringer, and 4" between stringers. The rivet spacing will be the same in the upper flange as in the lower.

Art. 15. Bottom Lateral System.

Lateral L_0L_1 is composed of four angles $4'' \times 3'' \times \frac{3}{8}''$. Area $= 9.92^{\square}''$.

Maximum stress $= 106950^{\#}$

Allowable unit stress $= 18000^{\#}$ (Cooper par. 31)

Required area $= 106950 \div 18000 = 5.94^{\square}''$

Efficiency $= 9.92 \div 5.94 = 167\%$.

Lateral L_1L_2 is composed of four angles $3'' \times 3'' \times \frac{3}{8}''$. Area $= 8.44^{\square}''$ Max. stress $= 81470^{\#}$

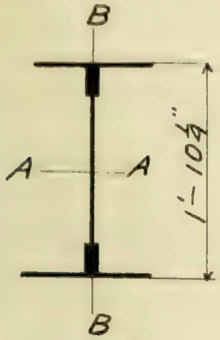
Required area $= 81470 \div 18000 = 4.5^{\square}''$

Efficiency $= 8.44 \div 4.5 = 186\%$

The remainder of the laterals have the same section as L_1L_2 and have smaller stresses, hence have higher efficiencies than the above.

The lateral struts are composed of four angles $6'' \times 3\frac{1}{2}'' \times \frac{3}{8}''$, laced. The angles are

spaced $24\frac{1}{4}$" back to back.



$I_{A.A.} = 4(3.34 + 10.36^2 \times 3.42) = 1482$

$I_{B.B.} = 4(12.86 + 2.17^2 \times 3.42) = 115.8$

$r_{B.B.} = \sqrt{\frac{115.8}{13.68}} = 8.7$

$l = 12 \times 20 = 240''$

The greatest stress is that in strut $L_1L_1 = +69000^{\#}$

Allowable unit stress $= 13000 - 60\frac{240}{8.7} = 11345^{\#}$

Required area $= 69000 \div 11345 = 6^{\square''}$

Efficiency $= 13.68 \div 6 = 228\%$

Lateral Connections.

Joint L_1

(a) Strut L_1L_1 Max. stress $= 69000^{\#}$

Shearing value of $\frac{7}{8}$" field rivets $= 2886^{\#}$

Required number rivets $= 6900 \div 2886 = 24$

Actual number of rivets used $= 24$

Efficiency of connection $= 100\%$.

(b) Diagonal L_1L_2 Max. stress $= 81470^{\#}$

Number rivets required $= 81470 \div 2886 = 29$

Number rivets used $= 16$

Efficiency $= 16 \div 29 = 55\%$

Joint L_2

(a) Strut L_2L_2. Max. stress $= 57550^{\#}$

Number of rivets required $= 57550 \div 2886 = 20$

Number rivets used $= 16$

Efficiency of connection $= 16 \div 20 = 80\%$

Floor Beam Reaction at Portal

Assume wt. per ft. of girder in approach span as 500# Reaction = 19.5 × 500# = 9750#

Reaction of stringers in panel $U_1 U_2$ = ½ × 4600# = 2300#

Reaction due to track = 250(11.5 + 19.5) = 7750#

Total dead load reaction = 9750 + 2300 + 7750 = 19800#

The max. live load reaction is produced by the uniform load = 3500 (11.5 × 19.5) = 108500#

Total reaction = 19800# + 108500# = 128,300#

Dead Load Stresses.

Stress in A.B. = −1.36 × 19800 = −26928#

" " A.C. = +.933 × 19800 = +18473#

" " B.C. = +19800#

" " B.D = −.933 × 19800 = −18473#

Live Load Stresses.

Stress in A.B = −1.36 × 108500 = −147,560#

" " A.C. = +.933 × 108500 = +101,230#

" " B.C. = +108,500#

" " B.D = −.933 × 108500# = 101,230#

Allowable unit tensile stress = 12000#

" " compressive " = $13000 - 60\frac{l}{r}$.

Member A.B. is composed of 4 Ls 6" × 4" × ¾"

Deduct from gross area 1.5□" for 2 − 1" holes.

Net area = 16.88 − 1.5 = 15.38□"

Required area = 174490 ÷ 12000 = 14.54□"

Efficiency of member 15.38 ÷ 14.59 = 105%

Joint L_3

(a) Strut L_3L_3 Max. stress = 37350#

Number rivets required = 37350 ÷ 2886 = 13

Number rivets used = 16

Efficiency of connection = 16 ÷ 13 = 123%

(b) Diagonal L_3U_4. Max. stress = 35700#

Number rivets required = 35700 ÷ 2886 = 13

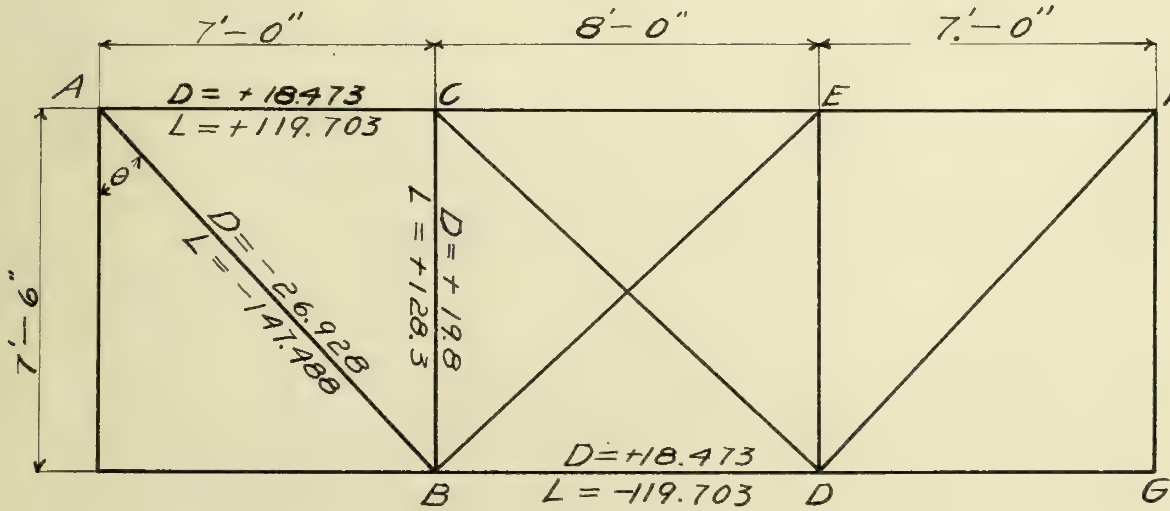
Number rivets used = 16

Efficiency of connection = 16 ÷ 13 = 123%

Art. 17 Top Lateral System.

The top lateral system is not designed to take any stress. Angles of minimum section, i.e. $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times \frac{3}{8}''$ are used.

Art. 18 Portal.



Sec θ = 1.36   Tan. θ = .933

Member A.C.

This member is composed of two angles $6'' \times 6'' \times \frac{3}{4}''$. Area = 16.88□″, l = 84,″ r = 2.73.″

Max. stress = 119,700#

Allowable unit stress = $13000 - 60\frac{84}{2.73} = 11154$#

Required area = 119700 ÷ 11154 = 10.7□″

Efficiency of member = 16.88 ÷ 10.7 = 158%

Member B.D.

This member is the same as A.C.

Max. stress = −119700.# Efficiency = 158%

Required area = 119700 ÷ 12000 = 9.98

Efficiency = 15.38 ÷ 9.98 = 154%

Member B.C.

This member is composed of two angles $4'' \times 4'' \times \frac{5}{8}''$. Area = 9.22□″. l = 90,″ r = 1.2″

Max. stress = +128300#

Allowable unit stress = $13000 - 60\frac{90}{1.2} = 8500$#

Required area = 128300 ÷ 8500 = 15□″

Efficiency = 9.22 ÷ 15 = 61%.

This member should have four angles of the given section instead of two as shown.

Connections.

(a) Member A.B. Max. stress = 174,490#

Shearing value of $\frac{7}{8}''$ rivets = 4329#

Number of rivets required = 174490 ÷ 4329 = 41

Number rivets used = 20

Efficiency of connection = 50%

(b) Member B.C. Max. stress = 128300#

Number rivets required = 128300 ÷ 4329 = 30

Number rivets used = 16

Efficiency of connection = 16 ÷ 30 = 53%

Connection to Post.

Max end shear = 128300#

Number rivets required = 128300 ÷ 2886 = 45

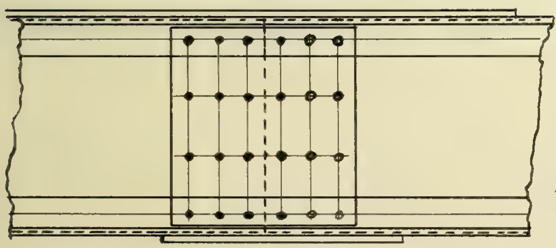
Number rivets used = 46

Efficiency of connection = 46 ÷ 45 = 100%

Art. 19 Chord Splices.

The chords must be spliced on all four sides with at least two rows of closely pitched rivets on each side of the joint. (Cooper Par. 65).

(a) Splice near U_1

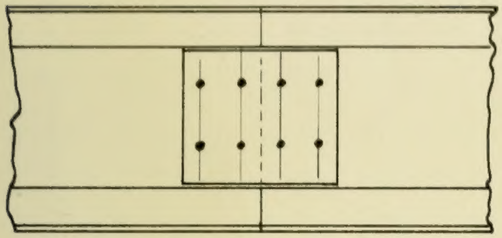


This splice has a plate on top and bottom of chord, one plate inside and two outside of each web, and three rows of rivets on each side of the joint

(b) Splice near U_3

This splice has no plate on under side of chord on account of the eye bar at

that place. The webs have a plate on each side and two rows of rivets each side of the joint. All the other joints are fully spliced, (except that no plate



can be placed on upper side of lower chord splices), having plates on both sides of each web, with the exception of of the splice at L_4 which has a plate only on the inside of the web. Each joint has from seven to ten rows of closely pitched rivets on each side of the joint.